ARL-TR-8269 ● JAN 2018

US Army Research Laboratory

An Automated Energy Detection Algorithm Based on Kurtosis-Histogram Excision

by Kwok F Tom

NOTICES

Disclaimers

ARL-TR-8269 ● JAN 2018

US Army Research Laboratory

An Automated Energy Detection Algorithm Based on Kurtosis-Histogram Excision

by Kwok F Tom
Sensors and Electron Devices Directorate, ARL

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED (From - To)**
January 2018	Technical Report	1 October 2016–30 September 2017

4. TITLE AND SUBTITLE
An Automated Energy Detection Algorithm Based on Kurtosis-Histogram Excision

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Kwok F Tom

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
US Army Research Laboratory
ATTN: RDRL-SER-E
2800 Powder Mill Road
Adelphi, MD 20783-1138

8. PERFORMING ORGANIZATION REPORT NUMBER
ARL-TR-8269

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
This report is the result of applying statistical processing techniques to the energy detection scenario of signals in the RF spectrum domain. The algorithm was developed after examining the collected RF spectral data files and revisiting a previous effort on prognostics and diagnostics on ball bearing fault detection. The algorithm automatically establishes a detection threshold based on the data of the RF spectrum measurement. It is able to determine the threshold level even when there are signals present in the RF spectrum.

15. SUBJECT TERMS
RF spectrum, detection threshold algorithm, histogram, kurtosis, statistical analysis

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			Kwok F Tom
Unclassified	Unclassified	Unclassified	UU	46	**19b. TELEPHONE NUMBER (Include area code)** (301) 394-2612

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

Contents

List of Tables

Preface

Energy detection in the RF spectrum is the most basic technique for signal detection. Typically, this requires establishing an energy detection threshold based on a noise-only condition (i.e., no signal present in the RF spectrum). Initially, the area of exploration for this report was to examine the potential of an automatic energy detection thresholding algorithm based on the RF measurement. It would not require the preliminary RF spectrum noise-only measurements to establish the energy detection threshold.

A series of RF spectrum measurements were collected at the US Army Research Laboratory in 2013. The data files contained different segments of the RF spectrum with various resolution bandwidths. In addition, the data files represented RF spectral conditions with and without RF signals. Some of these data files were used to examine a technique for automatic energy detection thresholding determination.

This report summarizes the development of the kurtosis histogram excision algorithm. RF spectrum of noise only is considered to be normal or Gaussian distributed. The histogram function converts the RF spectrum into a probability density function. The threshold is then determined through an iterative elimination of the high-bin histogram values until the kurtosis value has been reached. This is the fifth of 5 reports that detail the energy detection techniques examined with the recorded RF spectrum measurements.[1–4]

---

[1] Tom K. An automated energy detection algorithm based on morphological filter processing with a semi-disk structure. Adelphi (MD): Army Research Laboratory (US); 2018 Jan. Report No.: ARL-TR-8271.

[2] Tom K. An automated energy detection algorithm based on morphological filter processing with a modified watershed transform. Adelphi (MD): Army Research Laboratory (US); 2018 Jan. Report No.: ARL-TR-8270.

[3] Tom K. An automated energy detection algorithm based on morphological and statistical processing techniques. Adelphi (MD): Army Research Laboratory (US); 2018 Jan. Report No.: ARL-TR-8272.

[4] Tom K. An automated energy detection algorithm based on consecutive mean excision. Adelphi (MD): Army Research Laboratory (US); 2018 Jan. Report No.: ARL-TR-8268.

INTENTIONALLY LEFT BLANK.

1. Introduction

Energy detection is the simplest method of detecting a signal in the frequency spectrum. When doing so, a comparison is made between the frequency spectral component energy and a detection threshold level. Knowledge of the frequency spectrum is usually necessary to establish this detection threshold level. Various methods can be used to determine the detection threshold level, such as establishing the system noise statistics offline and setting the threshold for a given probability of detection versus probability of false alarm.

The goal of this study was to develop an algorithm that can analyze the frequency spectrum and establish a threshold value based on the spectral components. The automated processing employs techniques from statistical analysis and fault detection used in detecting ball-bearing faults. When monitoring vibrational data from a ball bearing, a fault indicator is typically set to a value of 3.5. When the RF spectrum does not contain a signal, it is considered to be noise only. The RF noise spectrum is typically assumed to have a Gaussian distribution. For a Gaussian distribution, the kurtosis has a value of 3. The algorithm developed sorts the spectral data set into a histogram representation. The highest bin value is deleted from the histogram until the remaining data set has a kurtosis value corresponding to the desired value.

2. Data Collection and Statistical Summary

The local RF spectrum was measured in 2013 on the rooftop of building 204 at the US Army Research Laboratory's (ARL's) Adelphi location. An Agilent N9342CN spectrum analyzer and a Discone antenna was used to collect RF spectrum data. This spectrum analyzer was operated under the control of a LabVIEW software program to acquire and store data with different resolution bandwidth (RBW) from 1 kHz to 1 MHz.

These data files represent various sizes of RF spectral coverage from 10 MHz up to 4 GHz. The number of data files for each spectral band varied. The larger RBW files were acquired over seconds of data acquisition time versus the small RBW files. Small RBW provides fine spectral resolution, but it impacts data acquisition time for spectral coverage and data size. Depending on the RBW and spectral coverage, a data file could require a few hours of acquisition.

Table 1 summarizes the data collection measurement files. The RF spectral bands covered the spectrum from 10 MHz to 4 GHz. In general, various spectral bands were measured with 4 RBW configuration. Data file size is inversely proportional

to the RBW. Data file size is proportional to the spectral band coverage. The data size varied from approximately 1 KSample to 4 MSample data points per file.

Table 1 Summary of the RF spectrum collection

Spectral band coverage	Number of RBW measurement	RBW
1.1–1.6 GHz	4	1 kHz, 10 kHz, 100 kHz, 1 MHz
2–3 GHz	4	1 kHz, 10 kHz, 100 kHz, 1 MHz
3–4 GHz	3	10 kHz, 100 kHz, 1 MHz
4–6 GHz	3	10 kHz, 100 kHz, 1 MHz
10 MHz–1 GHz	4	1 kHz, 10 kHz, 100 kHz, 1 MHz
10 MHz–2 GHz	4	1 kHz, 10 kHz, 100 kHz, 1 MHz
10 MHz–3 GHz	4	1 kHz, 10 kHz, 100 kHz, 1 MHz
10 MHz–4 GHz	4	1 kHz, 10 kHz, 100 kHz, 1 MHz
100 MHz–1 GHz	1	100 kHz

3. Statistical Processing

3.1 Statistical Analysis

Statistical analysis is the mathematical science dealing with the analysis or interpretation of data. The data analyst uses a few straightforward statistical techniques as a means of summarizing the collected data. These statistical techniques are under the area of descriptive statistics, which is a methodology to condense the data in quantitative terms.

In commercial prognostics and diagnostic vibrational monitoring applications, statistical techniques that are mainly used for alarm purposes in industrial plants are the statistical moments of order 2, 3, and 4. The probability density function (PDF) of the vibrational time series of a good bearing has a Gaussian distribution (also known as a normal distribution), whereas a damaged bearing results in a non-Gaussian distribution with dominant tails because of a relative increase in the number of high levels of acceleration. These techniques can be applied to the RF spectral data with a different interpretation of the results.[1]

3.1.1 Histogram

A histogram provides a tool to characterize the amplitude of a series of data into a visualization profile that can relate to the statistical features. The calculation is as follows:

Let d be the number of divisions needed to divide the range into, let $h_i$with $0 \leq i \leq d$ be the columns of the histogram, then

$$h_i = \sum_{j=0}^{n} \frac{1}{n} r_i(x_i), \forall i, 0 \leq i \leq d$$

$$r_i(x) = \begin{cases} 1, if \ \frac{i(max(x_i)-min(x_i))}{d} \leq x < \frac{(I+1)(max(x_i)-min(x_i))}{d} \\ 0, otherwise \end{cases}.$$

The histogram upper bound (h_U) and lower bound (h_L) are defined as

$$h_U = max(x_i) + \frac{\Delta}{2},$$

$$h_L = max(x_i) - \frac{\Delta}{2},$$

$$where \ \Delta = max(x_i) - \ min\left(\frac{x_i}{[n-1]}\right).$$

3.1.2 Moments

If these moments are calculated about the mean, they are called central statistical moments. The first and second moments are well known, being the mean and the variance, respectively. These are analogous to the first and second area moments of inertia with the area shape defined by the PDF. The third moment is termed skewness and the fourth moment is termed kurtosis. The general equation for the order of moment is as follows:

$$M_p = \frac{1}{N} \sum_{i=1}^{N} (x_i - \ \boldsymbol{\bar{x}})^p$$

$$where \ p \ is \ the \ order \ of \ the \ moment,$$

$$N \ is \ the \ number \ of \ data \ value,$$

$$i \ is \ the \ index \ of \ the \ data \ value, and$$

$$\boldsymbol{\bar{x}} \ is \ the \ mean \ value \ of \ the \ data \ set.$$

3.1.3 Mean

Mean is the most common measure of a statistical distribution. In this case, mean is the arithmetic average for a set of measurements.

$$\overline{\boldsymbol{x}} = \mu = \frac{1}{N}\sum_{i=1}^{N} x_i \,.$$

3.1.4 Variance

Variance is a measure of the dispersion of a waveform about its mean—also called the second moment of the measurements.

$$\sigma^2 = \frac{1}{N}\sum_{i=1}^{N}(x_i - \overline{\boldsymbol{x}})^2 \,.$$

3.1.5 Standard Deviation

Standard deviation is a measure of the variation of a set of data values. The standard deviation is defined as the square root of the variance moment.

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \overline{\boldsymbol{x}})^2} \,.$$

3.1.6 Kurtosis

Kurtosis is the fourth statistical moment, normalized by the standard deviation to the fourth power. It is a measure of whether the data are peaked or flat relative to a normal distribution. The noise in the RF spectrum is typically considered to have a normal distribution. The normal distribution has a value of 3.

$$\kappa = \frac{M_4}{\sigma^4} \,.$$

$$\kappa = \frac{\frac{1}{N}\sum_{i=1}^{N}(x_i - \overline{\boldsymbol{x}})^4}{\sigma^4} \,.$$

$$\kappa = \frac{1}{N\sigma^4}\sum_{i=1}^{N}(x_i - \overline{\boldsymbol{x}})^4 \,.$$

3.1.7 Maximum

"Max" is the largest value of a set of numbers.

$$y = \max[\boldsymbol{x}(n)].$$

3.1.8 Minimum

"Min" is the smallest value of a set of numbers.

$$y = \min[\boldsymbol{x}(n)].$$

3.1.9 Median

The statistical median is an order statistic that gives the "middle" value of a set of samples. Median is the middle value of a set of data values that divides the set into 2 groups. Half the groups exist below and half exist above this value.

3.1.10 Crest Factor (CF)

Crest factor (CF) is a measure of a waveform showing the ratio of peak values to the effective value. In other words, CF indicates how extreme the peaks are in a waveform.

$$Crest\ Factor = \frac{|x|_{peak}}{x_{rms}}.$$

Noise sources are characterized by their CF, which is the peak to average ratio of the noise. In a technical bulletin, XiTRON reported CF values between 5 and 7 for random noise.[2] For example, a 5:1 CF of the noise voltage is 20log5 = 14 dB. This is a measure of the quality of the noise distributions and one way to measure its Gaussian nature.[3] For the purpose of algorithm development, the CF equation was modified as follows:

$$Crest\ Factor = \frac{Max}{Median}.$$

3.2 Statistical Summary

There were 31 different groupings of the RF spectrum data measurements. The number of data files under each of the main groupings was varied. For the purpose of developing the algorithm, only a single data file was selected from each group. Each data file was processed to obtain the following characteristics: RBW, mean, standard deviation, median, max, min, kurtosis, and CF. A summary of the results is in Table 2.

The following results were noted:

- The smaller the RBW, the lower the noise floor. The equation for thermal noise power is $P = kTB$, where B is bandwidth. In this case, the RBW of 1 kHz has the lowest noise value. The RBW of 1 MHz has the highest noise value.

- Each 10-fold increase in bandwidth results in a 10-dB increase in noise power. This relationship is illustrated in this data set.

- The calculated mean and median values are very close for a given RF measurement configuration.

- A visual examination of the RF data files shows that there are 2 categories of data: signal plus noise and noise only. The kurtosis value correlates with the 2 categories. Typical kurtosis values for the noise-only files were 3 to 3.6.

Table 2 Statistical analysis of the RF spectrum measurements

Filename	Spectral Band	RBW	Mean	SD	Median	Max	Min	Kurtosis	CF
Air_test_1.1GHz_1.6GHzb_03_28_14_06_33_22	1.1 - 1.6 GHz	1000	-112.694	3.8444	-112.3	-101.2	-138.4	3.5571	11.1
Air_test_1.1GHz_1.6GHza_03_27_14_07_14_05	1.1 - 1.6 GHz	10000	-102.12	3.7226	-101.8	-91.69	-124.5	3.5134	10.11
Air_test_1.1GHz_1.6GHzc_03_31_14_06_47_26	1.1 - 1.6 GHz	100000	-90.9109	2.597	-90.75	-83.13	-101.2	3.0217	7.62
Air_test_1.1GHz_1.6GHzd_04_01_14_06_54_03	1.1 - 1.6 GHz	1000000	-80.5634	3.5741	-80.745	-55.36	-89.8	14.6861	25.385
Air_test_2GHz_3GHza_06_05_14_07_15_58	2 - 3 GHz	1000	-111.219	4.4991	-111.1	-77.55	-139	6.8918	33.55
Air_test_2GHz_3GHzb_05_29_14_06_28_28	2 - 3 GHz	10000	-101.006	4.1808	-100.8	-74.67	-122	6.1995	26.13
Air_test_2GHz_3GHzc_05_29_14_04_09_27	2 - 3 GHz	100000	-89.5666	3.4154	-89.68	-64.27	-100.3	13.2282	25.41
Air_test_2GHz_3GHzd_05_28_14_00_06_18	2 - 3 GHz	1000000	-79.6014	3.0753	-79.6	-58.74	-88.88	8.4466	20.86
Air_test_3GHz_4GHzb_06_12_14_06_30_17	3 - 4 GHz	10000	-100.51	3.7072	-100.2	-89.68	-123.7	3.5901	10.52
Air_test_3GHz_4GHzC_06_11_14_06_44_40	3 - 4 GHz	100000	-89.1625	2.5513	-89.075	-80.68	-102.3	3.0774	8.395
Air_test_3GHz_4GHzd_06_09_14_07_09_51	3 - 4 GHz	1000000	-79.0828	2.445	-78.94	-72.76	-88.5	2.9651	6.18
Air_test_4GHz_6GHza_04_24_14_07_05_26	4 - 6 GHz	1000	-107.559	4.1793	-107.2	-94.31	-136.3	3.3696	12.89
Air_test_4GHz_6GHzb_04_28_14_06_23_12	4 - 6 GHz	10000	-97.245	4.0398	-96.95	-84.05	-119.7	3.3249	12.9
Air_test_4GHz_6GHzc_04_29_14_06_48_42	4 - 6 GHz	100000	-85.9125	3.082	-85.77	-75.84	-98.78	2.9068	9.93
Air_test_10MHz_1GHza_04_17_14_07_09_30	10 MHz - 1 GHz	1000	-110.348	8.6126	-112.1	-28.37	-140.3	6.4788	83.73
Air_test_10MHz_1GHzb_04_21_14_07_17_44	10 MHz - 1 GHz	10000	-100.168	8.4775	-102	-27.95	-126.7	6.7602	74.05
Air_test_10MHz_1GHzc_04_22_14_06_39_58	10 MHz - 1 GHz	100000	-87.948	8.8113	-90.74	-27.28	-103.6	6.513	63.46
Air_test_10MHz_1GHzd_04_23_14_06_36_16	10 MHz - 1 GHz	1000000	-78.1054	8.3327	-80.59	-27.82	-89.88	7.5282	52.77
Air_test_10MHz_2GHzd_03_06_14_08_52_04	10 MHz - 2 GHz	1000	-111.275	6.9798	-112.1	-27.34	-138.3	9.5085	84.76
Air_test_10MHz_2GHzC_02_27_14_06_43_55	10 MHz - 2 GHz	10000	-100.894	7.0157	-101.8	-26.58	-125.9	10.4224	75.22
Air_test_10MHz_2GHzB_02_25_14_06_35_53	10 MHz - 2 GHz	100000	-89.242	6.7487	-90.59	-26.09	-102.4	12.7961	64.5
Air_test_10MHz_2GHz_02_20_14_06_55_36	10 MHz - 2 GHz	1000000	-78.8448	7.3203	-80.6	-26.54	-92.41	11.3819	54.06
Air_test_10MHz_3GHz_03_11_14_06_32_51	10 MHz - 3 GHz	1000	-111.373	6.1356	-111.8	-29.42	-140.5	11.0474	82.38
Air_test_10MHz_3GHzB_03_13_14_06_32_45	10 MHz - 3 GHz	10000	-100.787	6.3591	-101.4	-25.36	-125.9	11.7254	76.04
Air_test_10MHz_3GHzC_03_18_14_06_32_08	10 MHz - 3 GHz	100000	-89.1614	6.0257	-90.14	-24.16	-102.4	15.3376	65.98
Air_test_10MHz_3GHzd_03_20_14_08_09_07	10 Mhz - 3 GHz	1000000	-78.6492	6.7418	-80.8	-25.81	-90.38	13.0673	54.99
Air_test_10MHz_4GHza_04_10_14_07_01_22	10 MHz - 4 GHz	1000	-111.158	5.6813	-111.4	-28.22	-143.1	10.9573	83.18
Air_test_10MHz_4GHzb_04_11_14_06_10_18	10 MHz - 4 GHz	10000	-100.838	5.5851	-101.1	-26.85	-128	12.2576	74.25
Air_test_10MHz_4GHzc_04_15_14_07_01_09	10 MHz - 4 GHz	100000	-89.4431	5.1076	-90.03	-25.05	-103.5	18.317	64.98
Air_test_10MHz_4GHzd_04_16_14_06_42_27	10 MHz - 4 GHz	1000000	-79.0396	5.5441	-79.89	-26.72	-91.64	16.9073	53.17
Air_test_100MHz_1GHz_02_19_14_07_20_46	100 MHz - 1 GHz	100000	-88.0772	9.0701	-90.82	-23.91	-102.2	6.994	66.91

4. Algorithm

This development process was executed in MATLAB. Appendix A is the code used to process and generate the enclosed RF spectrum signature with the corresponding results of the detection threshold level. Basically, the algorithm generates a histogram of the RF spectrum file and examines the kurtosis statistics of the histogram. If the kurtosis is less than 3.6, the threshold is declared as the maximum value of the signature file. If it is greater than 3.6, the histogram bin information is sequentially eliminated. Starting with the highest bin value, the bins are deleted from the histogram until the kurtosis of the reduced histogram is less than 3.6. The following is a description of the detection thresholding level generation based on this technique:

1) Determine some statistical parameters of the spectral data (i.e., min, max, and kurtosis). Use these parameters (min and max) to determine the dynamic range of the spectral amplitude data.

2) Generate a histogram of the spectral amplitude data. The number of bins for the histogram is twice the dynamic range, as determined in step 1.

3) Store the results of the histogram sort into 2 arrays: Amplitudecount and Amplitudevalue.

4) Generate a new array called Amplitudediff. The new array is generated by taking the derivative of the Amplitudecount array.

5) Determine the smallest value in the Amplitudediff array. Then determine the location index in the Amplitudediff array that corresponds to this smallest value.

6) Search for the bin that corresponds to the smallest value in the Amplitudediff array. Establish the index to start the search for kurtosis that matches the criteria. Calculate the index count as the smallest Amplitudediff index + [0.6 × (max index – smallest Amplitudediff index)]. This step is performed to reduce the threshold search time.

7) If the initial kurtosis value is less than 3.6, then use the max value as the threshold.

8) If the initial kurtosis value is greater than 3.6, form a shortened copy of the histogram array. Using the Amplitude value array, form a new array by deleting the values starting at the index count from step 6.

9) Calculate the kurtosis on the new array. If this new kurtosis value is greater than 3.6, repeat step 8 by reducing the index count by 1. Repeat this until the kurtosis is less than 3.6. The bin value at this index is then selected to be the threshold value.

5. Conclusion

The kurtosis-histogram excision algorithm works well. Appendix A is the MATLAB code developed for this algorithm, which was based on prior work on vibrational analysis of ball bearings. In vibrational analysis, a typical kurtosis value of approximately 3.5 is used as a threshold to indicate that there is a deviation from a normal distribution. In this algorithm, the histogram processing reduces the RF spectrum data to a form where it can be compared to a normal distribution. In this case, a normal distribution represents a noise-only condition. This iterative algorithm starts by eliminating the high bin values in the histogram array and recalculating the kurtosis value. When the kurtosis value is less than 3.6, then the histogram bin value is declared as the RF spectrum threshold.

Appendix B displays the results of threshold overlaid on top of the RF spectrum signature. The graphs are intended to provide the reader with a qualitative sense of the effectiveness of the automatic detection threshold generation algorithm. The algorithm works well for the RF spectrum where there are signals present as well as for the RF spectrum that was judged to be noise only. A visual inspection of the graphs shows that the algorithm works well in minimizing the number of false alarms while permitting the detection of signals. Examination of the graphs shows that the spectrum is not necessarily flat over the spectral bands. This algorithm results in a single value threshold detection level across the spectral bands. Therefore, in some cases, the detection of certain signals may be degraded since the detection threshold is higher than necessary.

6. References

1. Tom KF. A primer on vibrational ball bearing feature generation for prognostics and diagnostics algorithms. Adelphi (MD): Army Research Laboratory (US); 2015 Mar. Report No.: ARL-TR-7230.

2. Crest factors and power analyzers. San Diego (CA): XiTRON Technologies; nd. Technical Brief TB 103 [accessed 2017 Nov 8]. http://www.xitrontech.com/assets/002/5788.pdf.

3. Noise: frequently asked questions. East Hanover (NJ): Noisewave; nd [accessed 2017 Nov 8]. http://www.noisewave.com/faq.pdf.

INTENTIONALLY LEFT BLANK.

Appendix A. MATLAB Code

```
function KurtosisThreshold2report()

% Make selection for data file to process
% SELECT = 1 to 31

SELECT = 31;


dir{1} = 'K:\CognitiveRadar\spectrum monitoring\data\building204-
4c085\Air_test_1.1GHz_1.6GHza\';
filename{1} = 'Air_test_1.1GHz_1.6GHza_03_27_14_07_14_05';

dir{2} = 'K:\CognitiveRadar\spectrum monitoring\data\building204-
4c085\Air_test_1.1GHz_1.6GHzb\';
filename{2} = 'Air_test_1.1GHz_1.6GHzb_03_28_14_06_33_22';

dir{3} = 'K:\CognitiveRadar\spectrum monitoring\data\building204-
4c085\Air_test_1.1GHz_1.6GHzc\';
filename{3} = 'Air_test_1.1GHz_1.6GHzc_03_31_14_06_47_26';

dir{4} = 'K:\CognitiveRadar\spectrum monitoring\data\building204-
4c085\Air_test_1.1GHz_1.6GHzd\';
filename{4} = 'Air_test_1.1GHz_1.6GHzd_04_01_14_06_54_03';

dir{5} = 'K:\CognitiveRadar\spectrum monitoring\data\building204-
4c085\Air_test_2GHz_3GHza\';
filename{5} = 'Air_test_2GHz_3GHza_06_05_14_07_15_58';

dir{6} = 'K:\CognitiveRadar\spectrum monitoring\data\building204-
4c085\Air_test_2GHz_3GHzb\';
filename{6} = 'Air_test_2GHz_3GHzb_05_29_14_06_28_28';

dir{7} = 'K:\CognitiveRadar\spectrum monitoring\data\building204-
4c085\Air_test_2GHz_3GHzc\';
filename{7} = 'Air_test_2GHz_3GHzc_05_29_14_04_09_27';

dir{8} = 'K:\CognitiveRadar\spectrum monitoring\data\building204-
4c085\Air_test_2GHz_3GHzd\';
filename{8} = 'Air_test_2GHz_3GHzd_05_28_14_00_06_18';

dir{9} = 'K:\CognitiveRadar\spectrum monitoring\data\building204-
4c085\Air_test_3GHz_4GHzb\';
filename{9} = 'Air_test_3GHz_4GHzb_06_12_14_06_30_17';

dir{10} = 'K:\CognitiveRadar\spectrum
monitoring\data\building204-4c085\Air_test_3GHz_4GHzC\';
filename{10} = 'Air_test_3GHz_4GHzC_06_11_14_06_44_40';

dir{11} = 'K:\CognitiveRadar\spectrum
monitoring\data\building204-4c085\Air_test_3GHz_4GHzd\';
filename{11} = 'Air_test_3GHz_4GHzd_06_09_14_07_09_51';
```

```
dir{12} = 'K:\CognitiveRadar\spectrum
monitoring\data\building204-4c085\Air_test_4GHz_6GHza\';
filename{12} = 'Air_test_4GHz_6GHza_04_24_14_07_05_26';

dir{13} = 'K:\CognitiveRadar\spectrum
monitoring\data\building204-4c085\Air_test_4GHz_6GHzb\';
filename{13} = 'Air_test_4GHz_6GHzb_04_28_14_06_23_12';

dir{14} = 'K:\CognitiveRadar\spectrum
monitoring\data\building204-4c085\Air_test_4GHz_6GHzc\';
filename{14} = 'Air_test_4GHz_6GHzc_04_29_14_06_48_42';

dir{15} = 'K:\CognitiveRadar\spectrum
monitoring\data\building204-4c085\Air_test_10MHz_1GHza\';
filename{15} = 'Air_test_10MHz_1GHza_04_17_14_07_09_30';

dir{16} = 'K:\CognitiveRadar\spectrum
monitoring\data\building204-4c085\Air_test_10MHz_1GHzb\';
filename{16} = 'Air_test_10MHz_1GHzb_04_21_14_07_17_44';

dir{17} = 'K:\CognitiveRadar\spectrum
monitoring\data\building204-4c085\Air_test_10MHz_1GHzc\';
filename{17} = 'Air_test_10MHz_1GHzc_04_22_14_06_39_58';

dir{18} = 'K:\CognitiveRadar\spectrum
monitoring\data\building204-4c085\Air_test_10MHz_1GHzd\';
filename{18} = 'Air_test_10MHz_1GHzd_04_23_14_06_36_16';

dir{19} = 'K:\CognitiveRadar\spectrum
monitoring\data\building204-4c085\Air_test_10MHz_2GHz\';
filename{19} = 'Air_test_10MHz_2GHz_02_20_14_06_55_36';

dir{20} = 'K:\CognitiveRadar\spectrum
monitoring\data\building204-4c085\Air_test_10MHz_2GHzB\';
filename{20} = 'Air_test_10MHz_2GHzB_02_25_14_06_35_53';

dir{21} = 'K:\CognitiveRadar\spectrum
monitoring\data\building204-4c085\Air_test_10MHz_2GHzC\';
filename{21} = 'Air_test_10MHz_2GHzC_02_27_14_06_43_55';

dir{22} = 'K:\CognitiveRadar\spectrum
monitoring\data\building204-4c085\Air_test_10MHz_2GHzd\';
filename{22} = 'Air_test_10MHz_2GHzd_03_06_14_08_52_04';

dir{23} = 'K:\CognitiveRadar\spectrum
monitoring\data\building204-4c085\Air_test_10MHz_3GHz\';
filename{23} = 'Air_test_10MHz_3GHz_03_11_14_06_32_51';

dir{24} = 'K:\CognitiveRadar\spectrum
monitoring\data\building204-4c085\Air_test_10MHz_3GHzB\';
filename{24} = 'Air_test_10MHz_3GHzB_03_13_14_06_32_45';

dir{25} = 'K:\CognitiveRadar\spectrum
monitoring\data\building204-4c085\Air_test_10MHz_3GHzC\';
```

```
filename{25} = 'Air_test_10MHz_3GHzC_03_18_14_06_32_08';

dir{26} = 'K:\CognitiveRadar\spectrum
monitoring\data\building204-4c085\Air_test_10MHz_3GHzd\';
filename{26} = 'Air_test_10MHz_3GHzd_03_20_14_08_09_07';

dir{27} = 'K:\CognitiveRadar\spectrum
monitoring\data\building204-4c085\Air_test_10MHz_4GHza\';
filename{27} = 'Air_test_10MHz_4GHza_04_10_14_07_01_22';

dir{28} = 'K:\CognitiveRadar\spectrum
monitoring\data\building204-4c085\Air_test_10MHz_4GHzb\';
filename{28} = 'Air_test_10MHz_4GHzb_04_11_14_06_10_18';

dir{29} = 'K:\CognitiveRadar\spectrum
monitoring\data\building204-4c085\Air_test_10MHz_4GHzc\';
filename{29} = 'Air_test_10MHz_4GHzc_04_15_14_07_01_09';

dir{30} = 'K:\CognitiveRadar\spectrum
monitoring\data\building204-4c085\Air_test_10MHz_4GHzd\';
filename{30} = 'Air_test_10MHz_4GHzd_04_16_14_06_42_27';

dir{31} = 'K:\CognitiveRadar\spectrum
monitoring\data\building204-4c085\Air_test_100MHz_1GHz\';
filename{31} = 'Air_test_100MHz_1GHz_02_19_14_07_20_46';

str_meta =
sprintf('%s%s.mspecrawdata',dir{SELECT},filename{SELECT});
str_data =
sprintf('%s%s.specrawdata',dir{SELECT},filename{SELECT});

% Get metadata on selected data file

fid_meta = fopen(str_meta);
META = textscan(fid_meta,'%s');
ave = META{1}{1};
ref = META{1}{2};
attn = META{1}{3};
rbw = META{1}{4};


% Read in data file

fid_data = fopen(str_data);
g=0;
f=0;
a=0;
while(g==0)
    ft=fgetl(fid_data);
    f=[f,str2num(ft)];
    at=fgetl(fid_data);
    a=[a,str2num(at)];
    g=feof(fid_data);
end
```

```
f=f(2:end);
a=a(2:end);

% Plot data file

figure(1);
plot(f/1e6,a);
axis tight;
grid;
xlabel('Frequency (MHz)');
ylabel('Power (dBm)');
title(strcat(rbw,'--',ave,'--',ref,'--
',attn),'Interpreter','none');

% Determine some statistics values for data

M = mean(a);

Med = median(a);

S = std(a);

Max = max(a);

Min = min(a);

Kurt = kurtosis(a);

Range = abs(Min - Max);

Number = floor(Range);

Bins = Number * 2;

disp([M S Med Max Min Kurt]);



[Amplitudearray X] = hist(a,Bins);

% Plot sorted amplitdude data array

figure(2);

plot(Amplitudearray);



% This algorithm uses the histogram and kurtosis processing to
determine
```

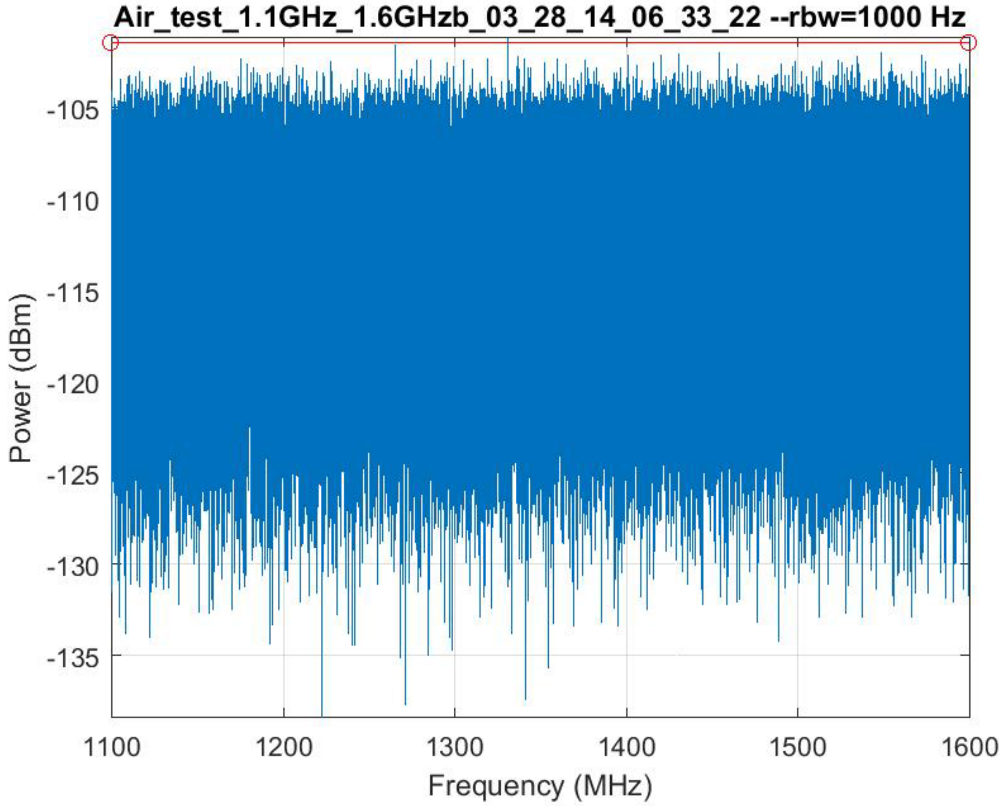
Approved for public release; distribution is unlimited.

```
% the threshold.  The RF spectrum is sorted by the histogram.
There is an
% iterative elimination of the highest values from the histogram
until the
% criteria of the kurtosis of the newly formed array is less than
3.6.  The
% value of 3.6 is somewhat an empirical obervation from
vibrational
% analysis to determine when the signal has deviated from a
normal
% distribution or noise only condition.

index = Bins;


[Amplitudecount Amplitudevalue] = hist(a,Bins);
Histovalue = a;
indexvalue = 1;

% Take derivative of the histogram values and plot array

figure(4);
Amplitudediff = diff(Amplitudecount);
plot (Amplitudediff);

% Find the smallest value from the derivatives

Amplitudediffmin = min(Amplitudediff);

% Determine starting index of histogram array to start
elimination

for indexcount = 1:index-1

    if Amplitudediff((indexcount)) == Amplitudediffmin
        indexsubtraction = index - floor((index -
indexcount)*.6);
    end

end

    for m = 1:index
        for n= 1:Amplitudecount(m);
            Histovalue(indexvalue) = Amplitudevalue(m);
            indexvalue = indexvalue + 1;
        end
    end

Histolength = length(Histovalue);

ProdKurt = kurtosis(Histovalue);
```

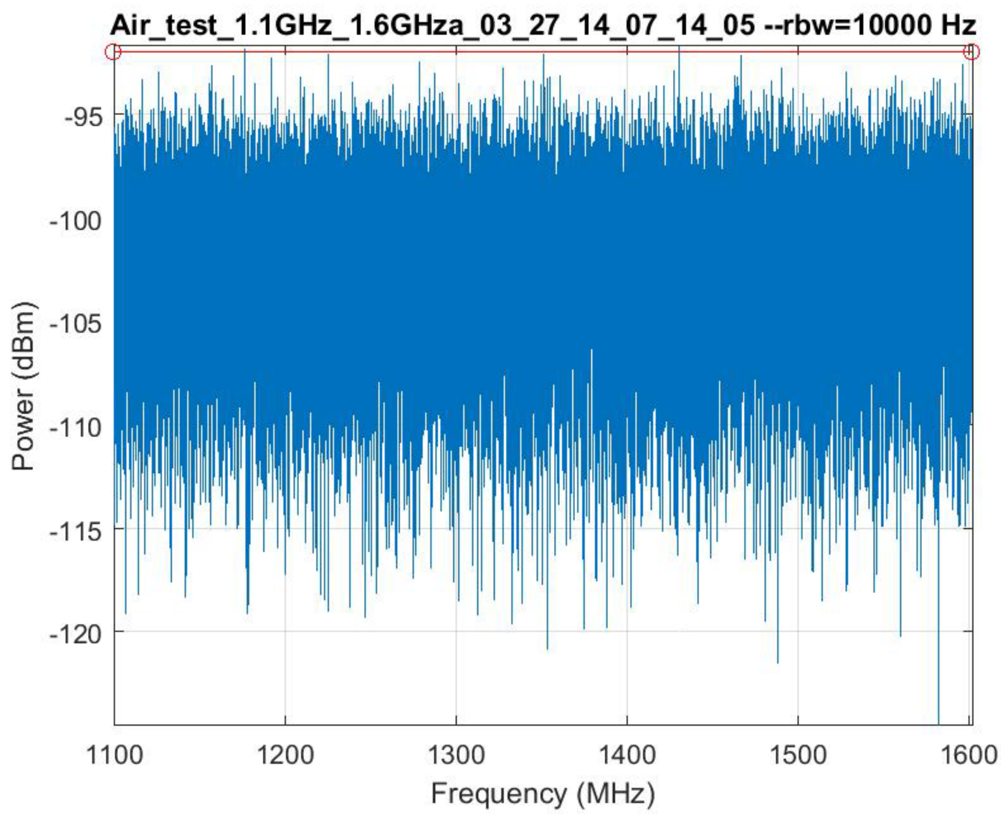
```
 % Set the starting point for elimination from the histogram
array

index = indexsubtraction;

% Check to see if kurtosis value of the newly formed histogram is
below
% 3.6.  It criteria has been meet, then the threshold is the
value of the
% histogram bin.

if ProdKurt < 3.6

 index = Bins;
else

% While kurtosis value is greater than 3.6, eliminate next bin
value and
% form reduced array for kurtosis calculation

    while ProdKurt > 3.6

       Histovalue = [];

       index = index - 1;

       indexvalue = 1;

 % Form a new array

       for m = 1:index

                for n= 1:Amplitudecount(m);
                     Histovalue(indexvalue) = Amplitudevalue(m);
                     indexvalue = indexvalue +1;
                end
       end
        Histolength = length(Histovalue);

% Recalculat kurtosis on the reduce histogram array

        ProdKurt = kurtosis(Histovalue);


    end
end

 disp(index);
 disp(ProdKurt);
 disp(X(index));

% Plot RF spectrum and the threshold
```

```
figure(3);

plot(f/1e6,a);
axis tight;
grid;
xlabel('Frequency (MHz)');
ylabel('Power (dBm)');
title(strcat(filename(SELECT),' --  ',rbw,'
Hz'),'Interpreter','none');
hold;
xa = [f(1)/1e6 f(end)/1e6];
yb = [X(index) X(index)];
plot(xa,yb,'r-o');

% Save results to data file

hold off;
lab = num2str(SELECT);
label = strcat('Kurtosis-Figure',lab,'.jpg');
saveas(gcf,label);




end
```

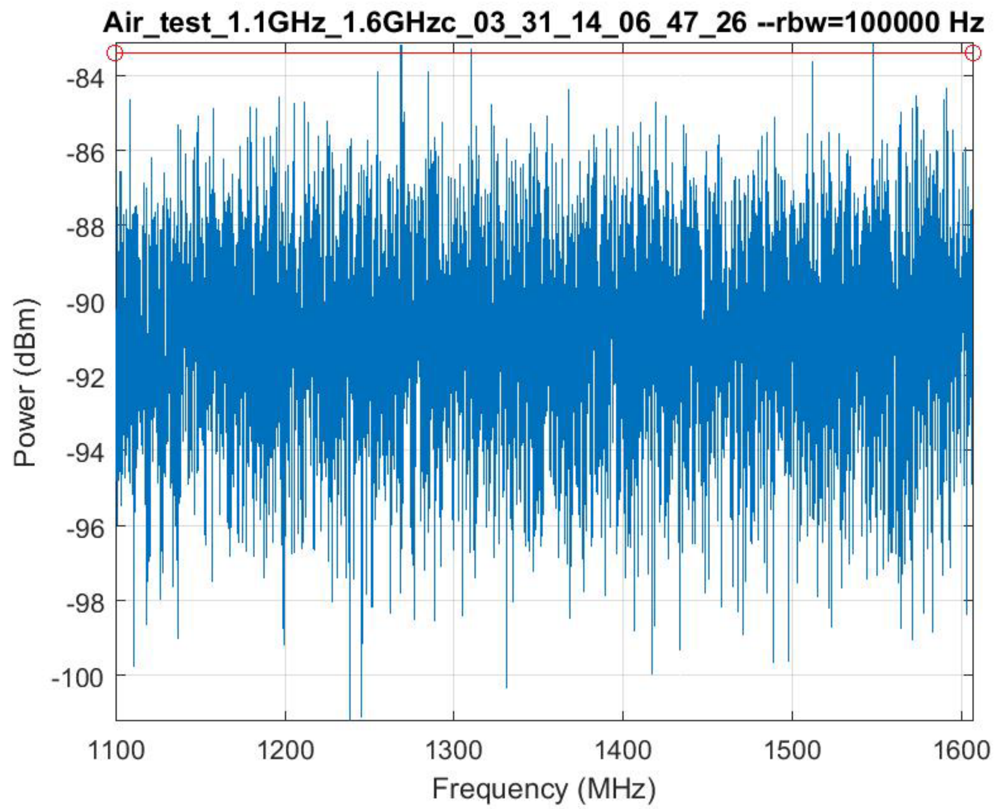
Appendix B. Graphs of RF Spectrum Files Calculated Detection Threshold



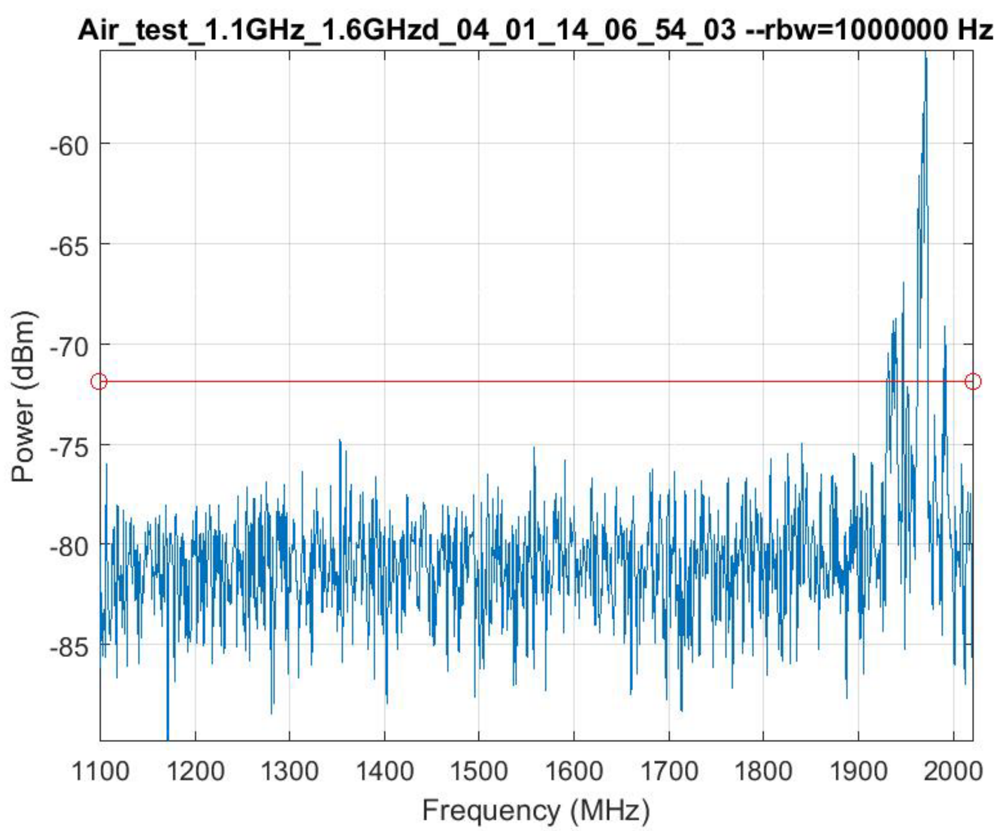
Air_test_1.1GHz_1.6GHzb_03_28_14_06_33_22 --rbw=1000 Hz
Power (dBm)
-105
-110
-115
-120
-125
-130
-135
1100
1200
1300
1400
1500
1600
Frequency (MHz)



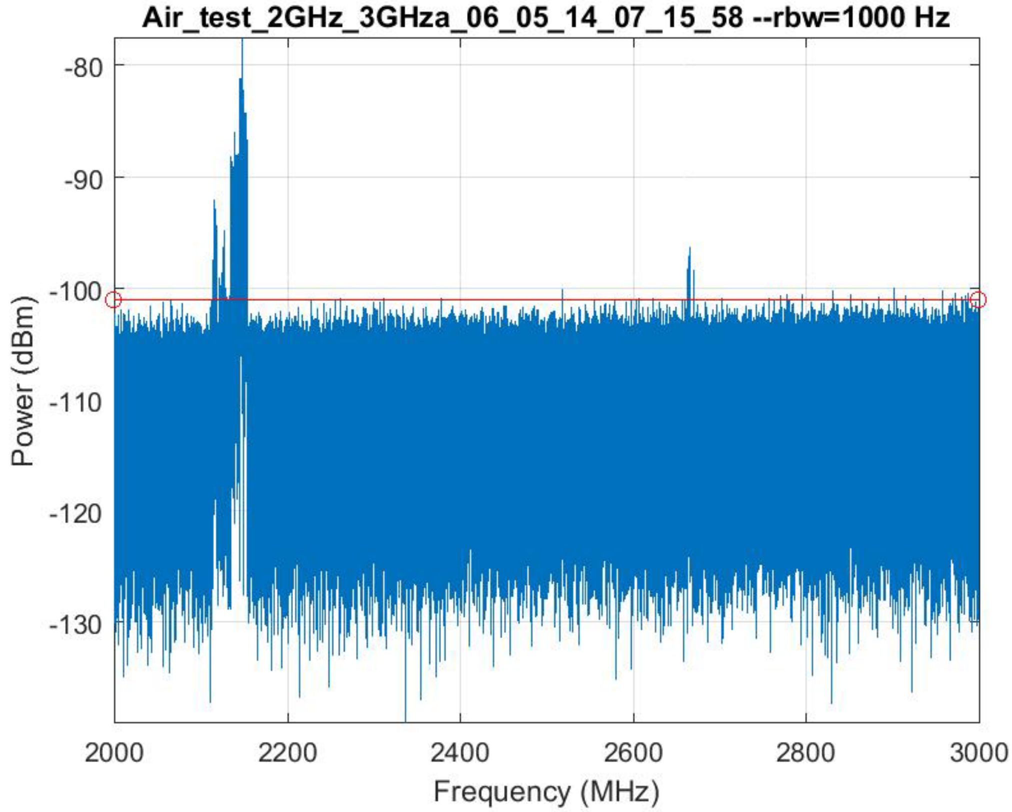
Air_test_1.1GHz_1.6GHza_03_27_14_07_14_05 --rbw=10000 Hz
Power (dBm)
-95
-100
-105
-110
-115
-120
1100
1200
1300
1400
1500
1600
Frequency (MHz)



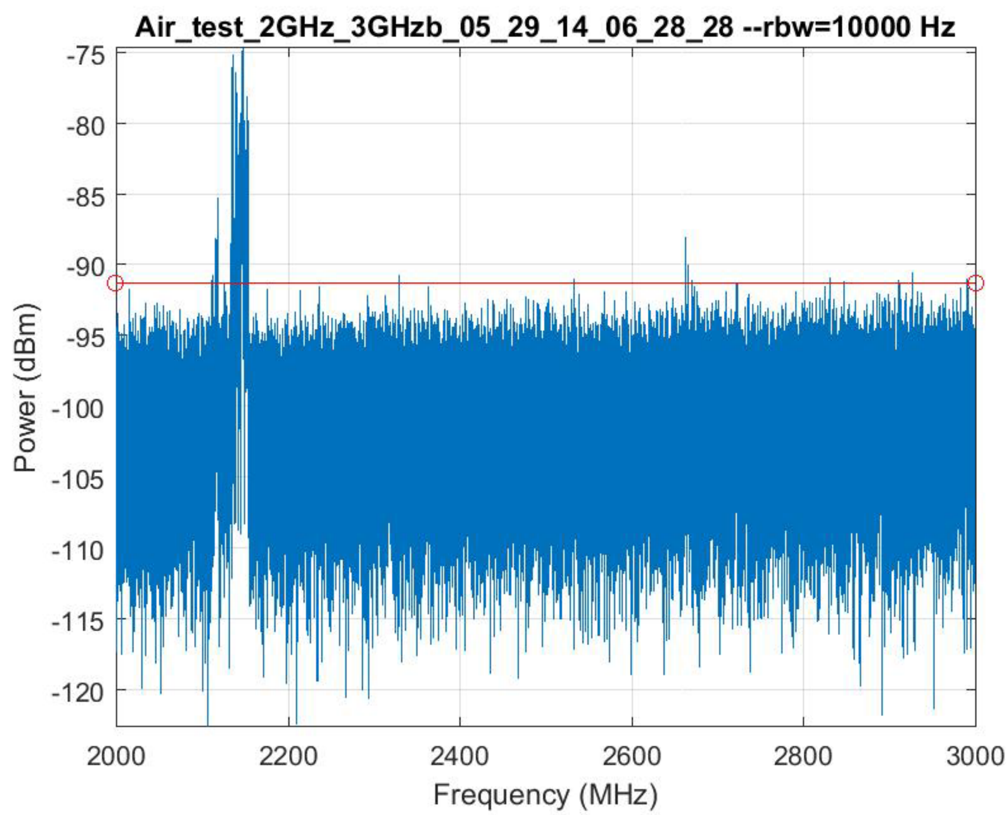
Air_test_1.1GHz_1.6GHzc_03_31_14_06_47_26 --rbw=100000 Hz
-84
-86
-88
-90
-92
-94
-96
-98
-100
Power (dBm)
1100
1200
1300
1400
1500
1600
Frequency (MHz)



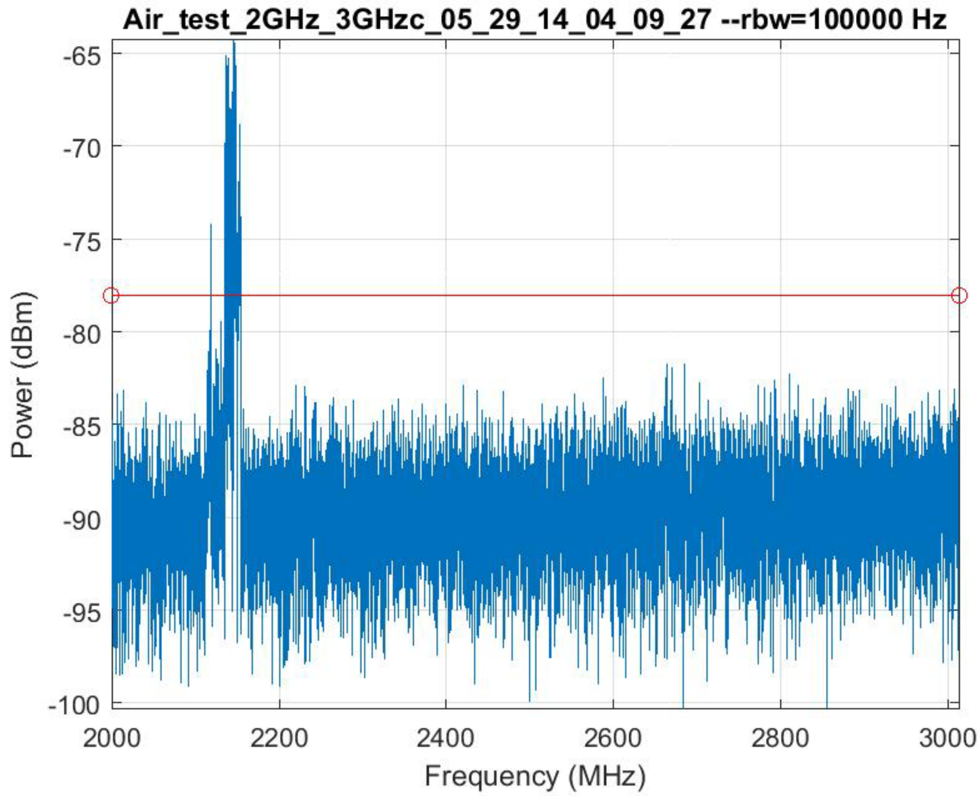
Air_test_1.1GHz_1.6GHzd_04_01_14_06_54_03 --rbw=1000000 Hz
-60
-65
-70
-75
-80
-85
Power (dBm)
1100
1200
1300
1400
1500
1600
1700
1800
1900
2000
Frequency (MHz)

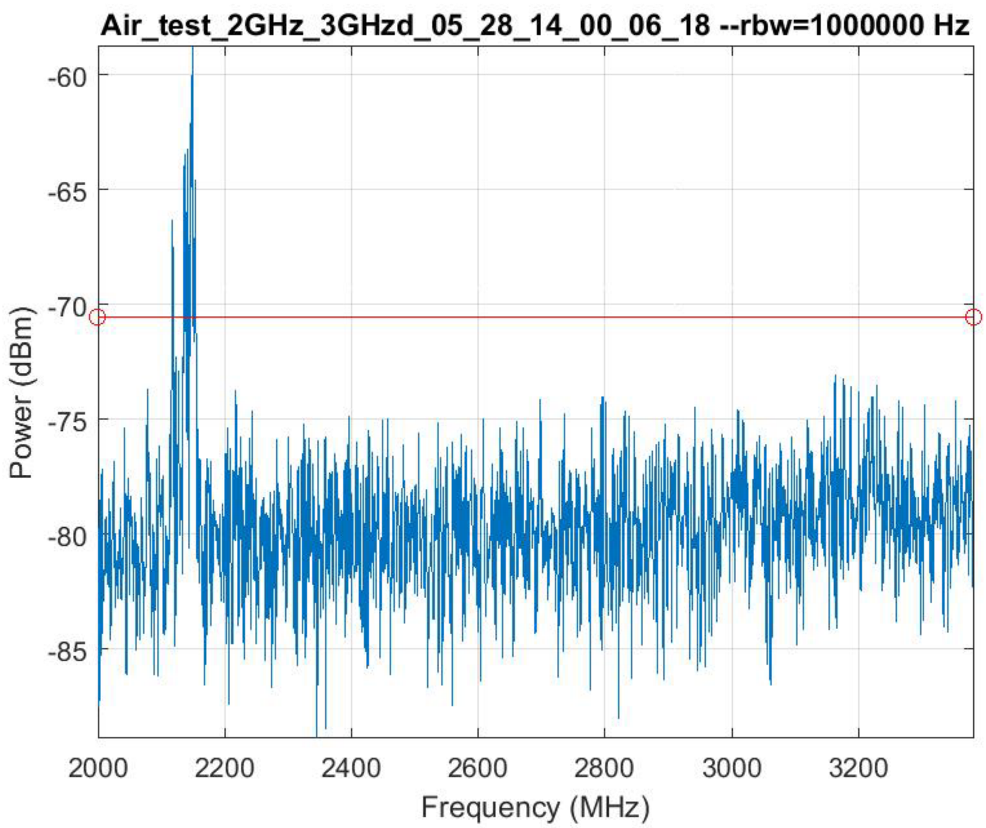


Air_test_2GHz_3GHza_06_05_14_07_15_58 --rbw=1000 Hz
-80
-90
-100
-110
-120
-130
Power (dBm)
2000
2200
2400
2600
2800
3000
Frequency (MHz)

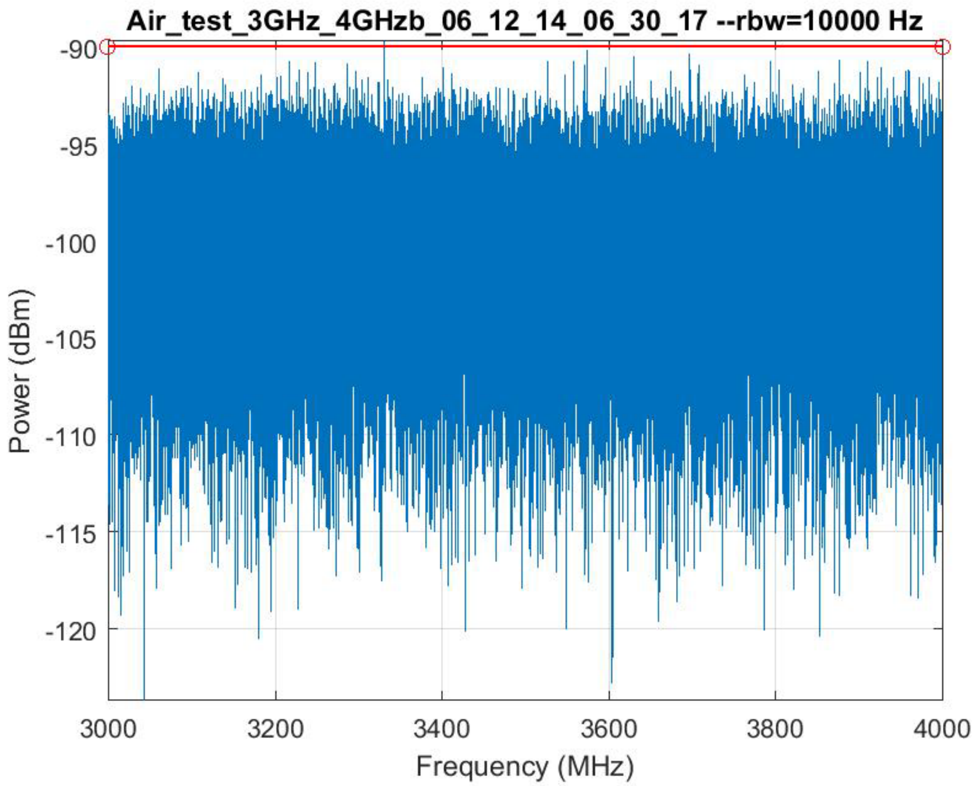


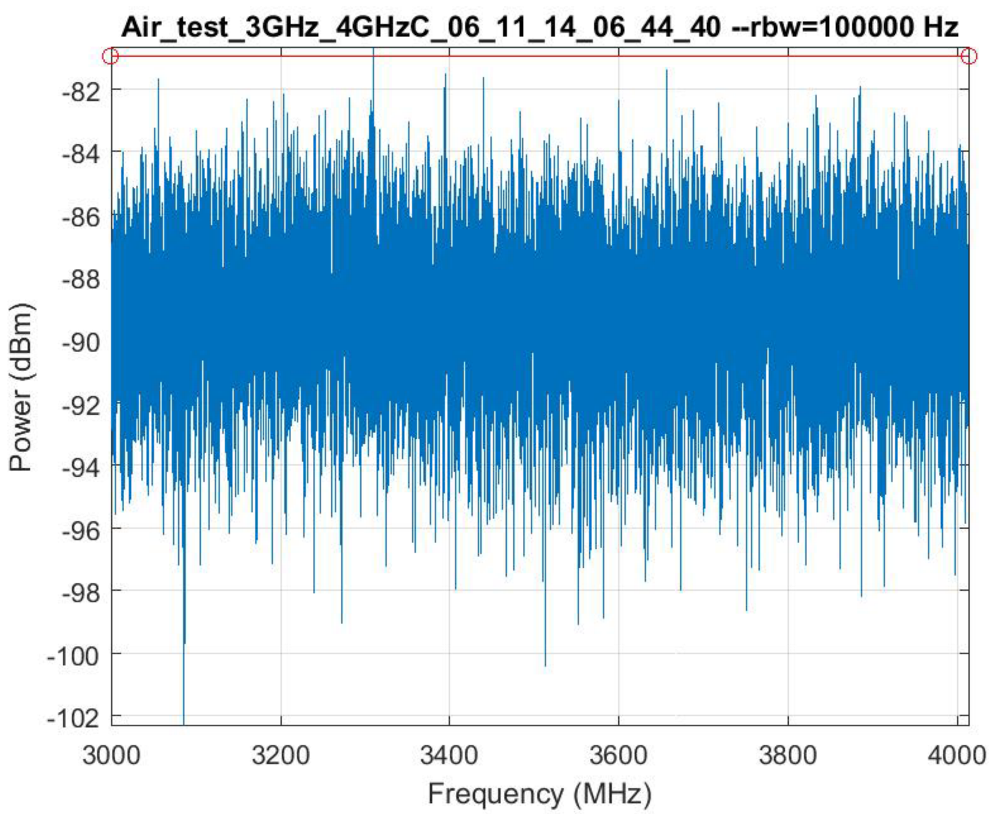
Air_test_2GHz_3GHzb_05_29_14_06_28_28 --rbw=10000 Hz
-75
-80
-85
-90
-95
-100
-105
-110
-115
-120
Power (dBm)
2000
2200
2400
2600
2800
3000
Frequency (MHz)

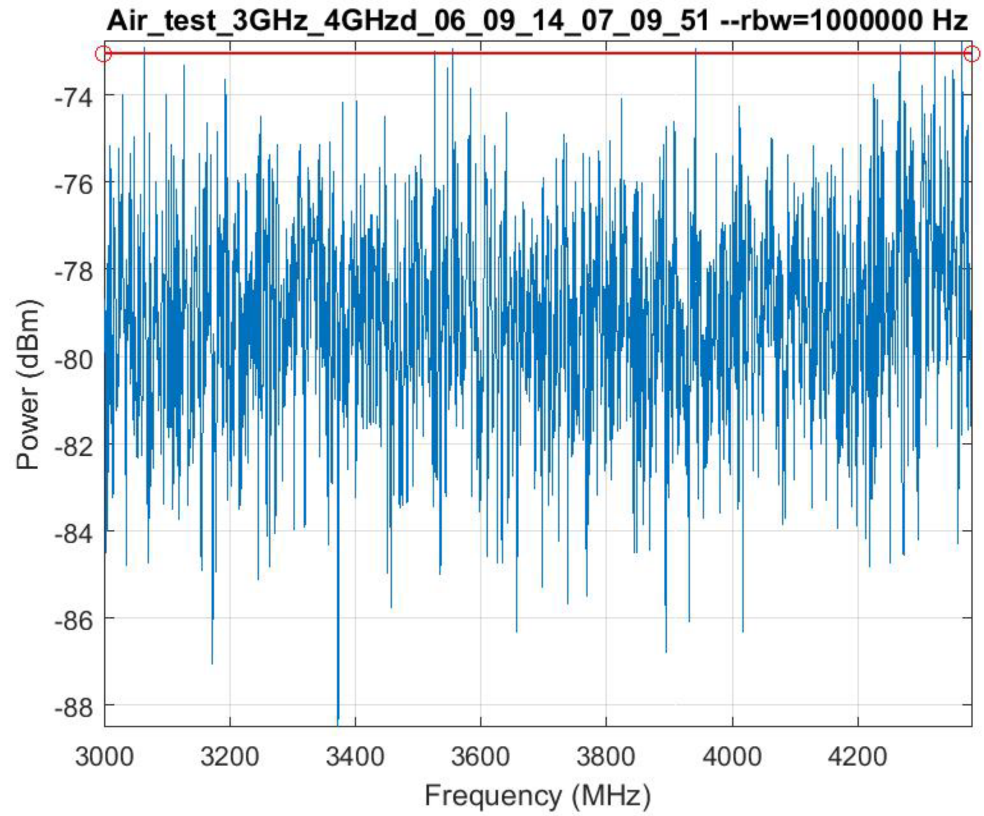


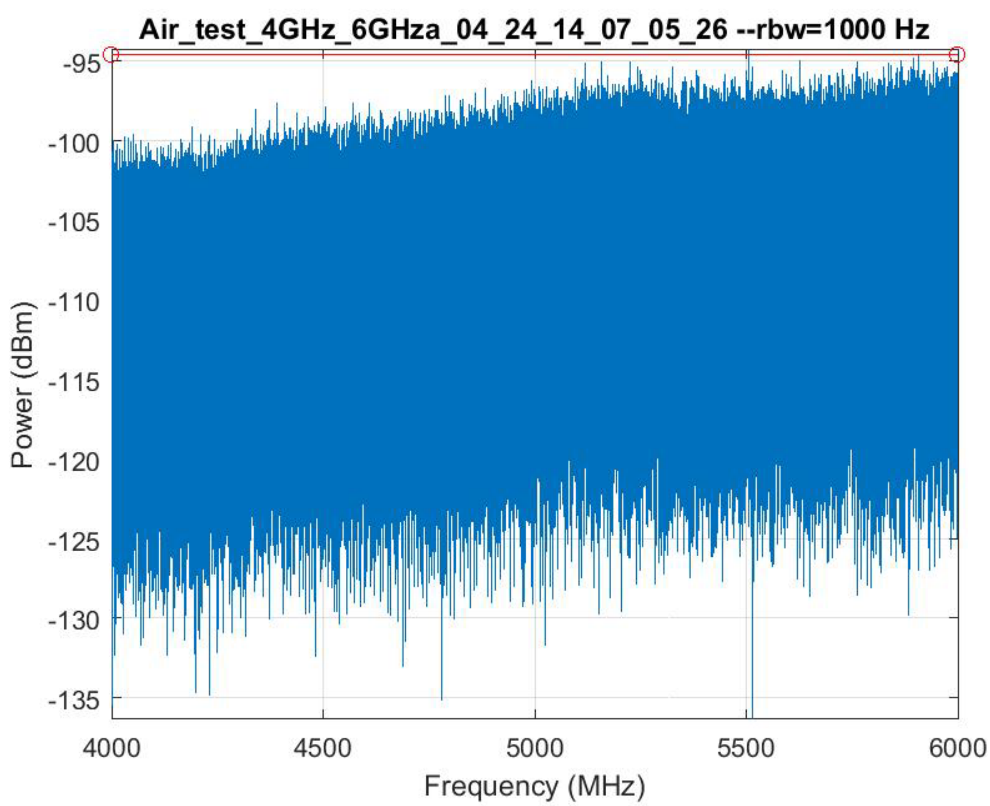


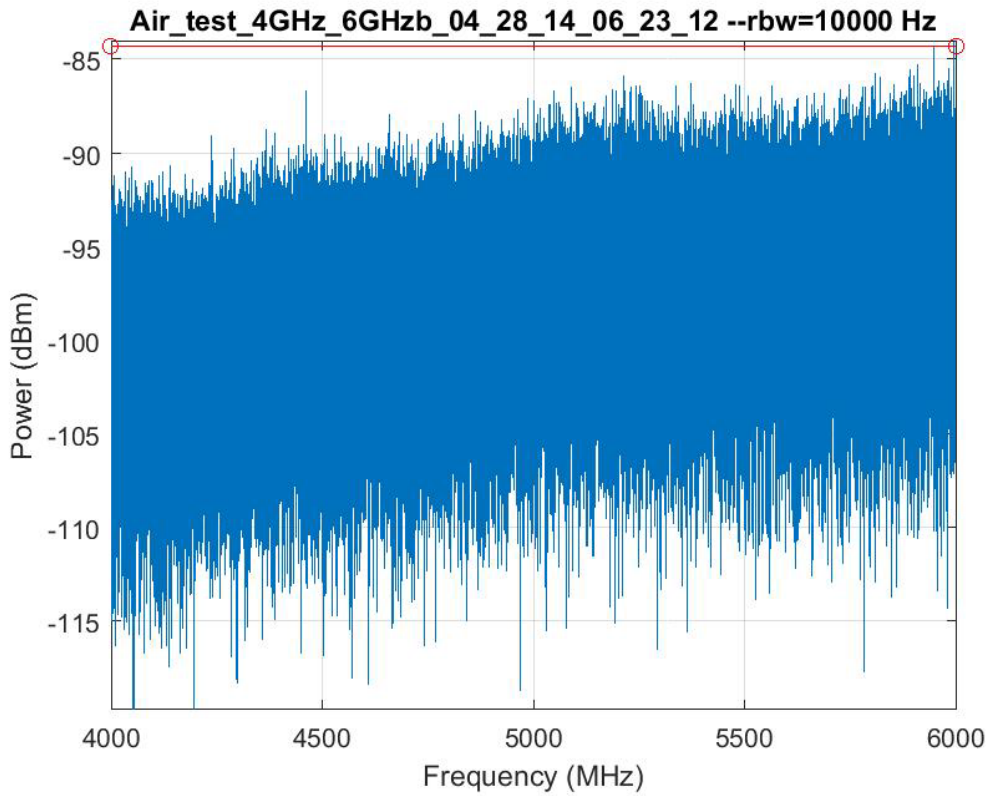
Approved for public release; distribution is unlimited.

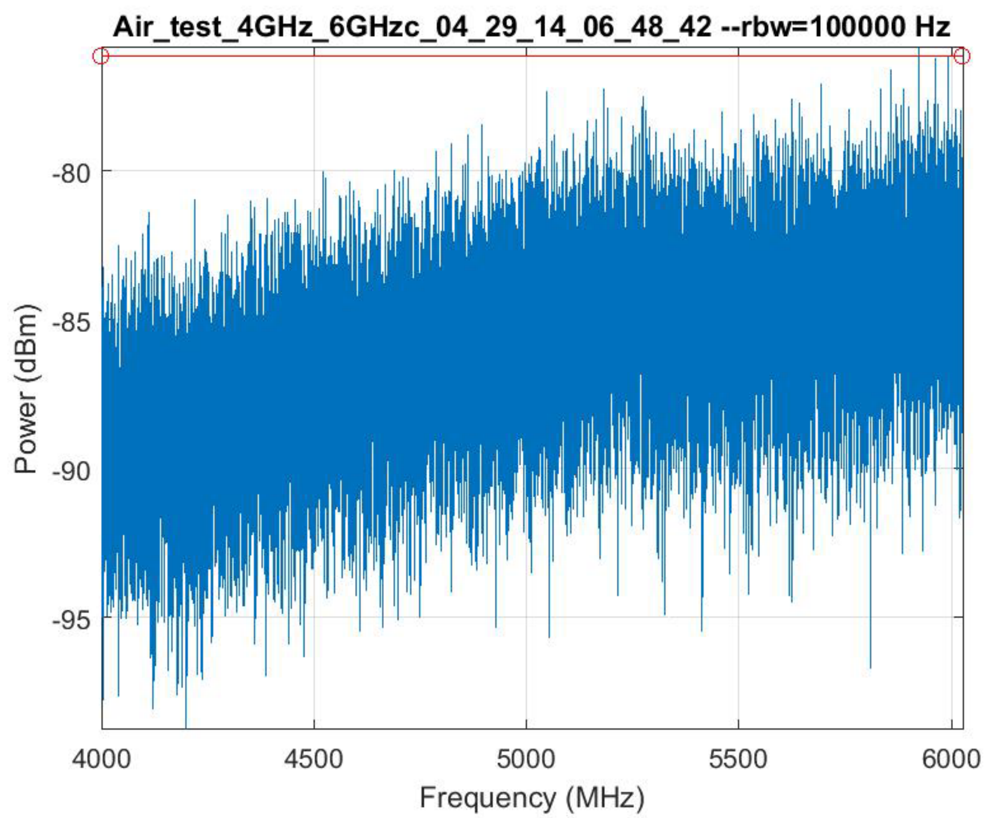

Air_test_3GHz_4GHzb_06_12_14_06_30_17 --rbw=10000 Hz
-90
-95
-100
-105
-110
-115
-120
Power (dBm)
3000
3200
3400
3600
3800
4000
Frequency (MHz)

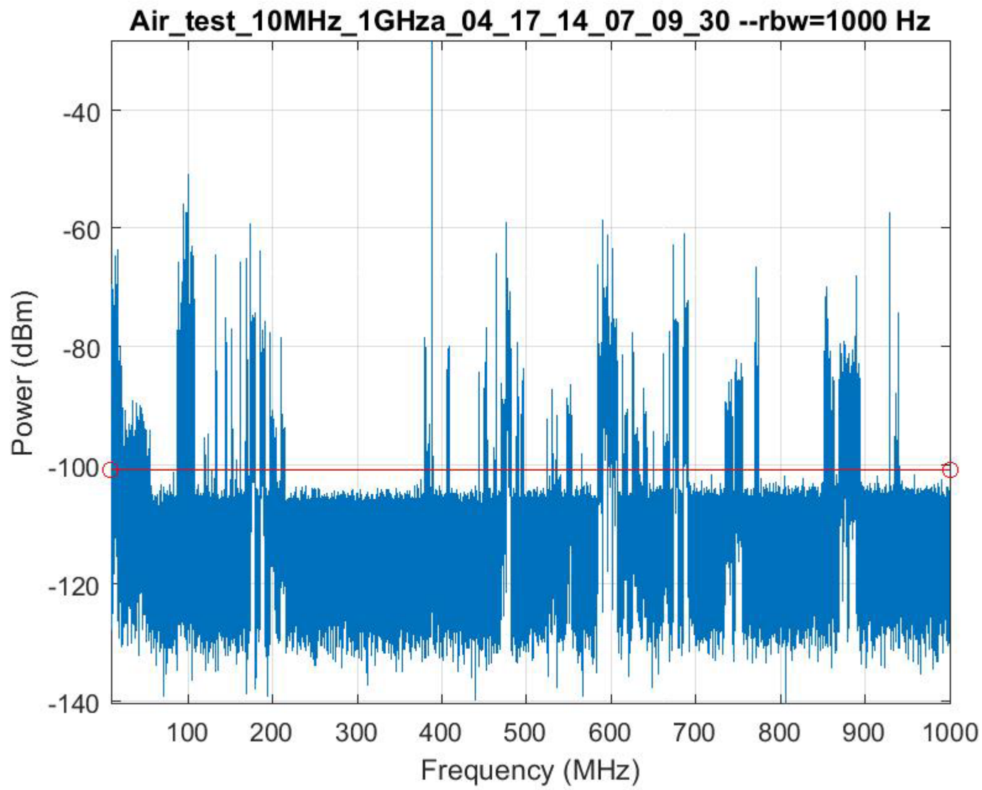

Air_test_3GHz_4GHzC_06_11_14_06_44_40 --rbw=100000 Hz
-82
-84
-86
-88
-90
-92
-94
-96
-98
-100
-102
Power (dBm)
3000
3200
3400
3600
3800
4000
Frequency (MHz)

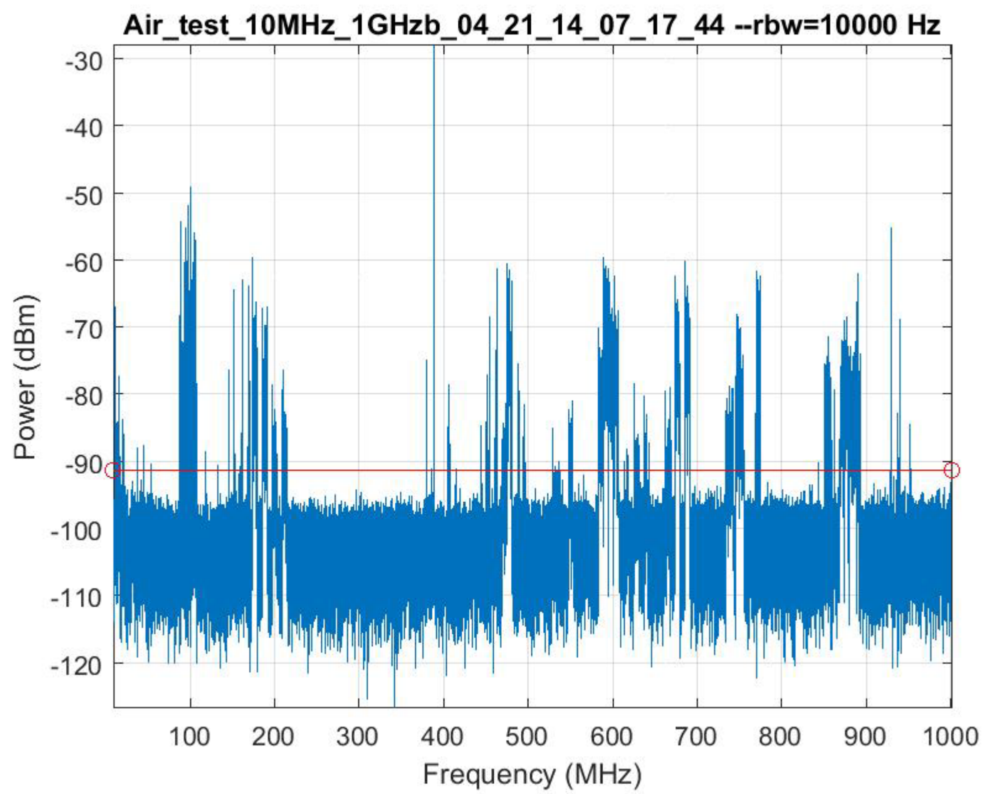

Air_test_3GHz_4GHzd_06_09_14_07_09_51 --rbw=1000000 Hz
Power (dBm)
-74
-76
-78
-80
-82
-84
-86
-88
3000
3200
3400
3600
3800
4000
4200
Frequency (MHz)

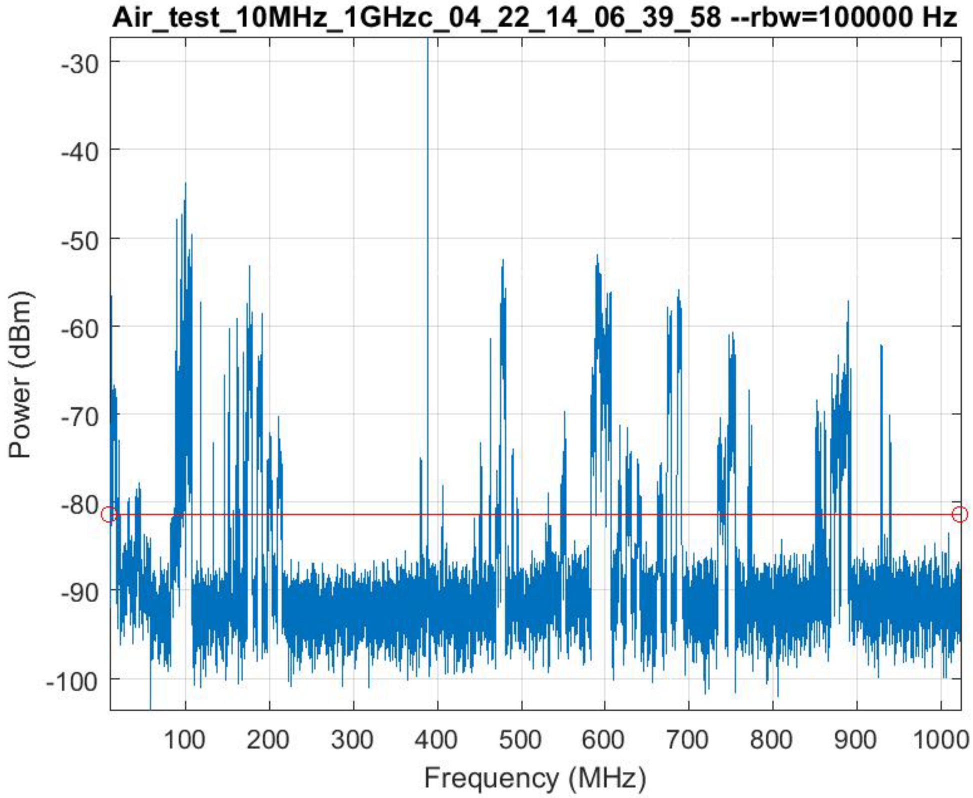

Air_test_4GHz_6GHza_04_24_14_07_05_26 --rbw=1000 Hz
Power (dBm)
-95
-100
-105
-110
-115
-120
-125
-130
-135
4000
4500
5000
5500
6000
Frequency (MHz)

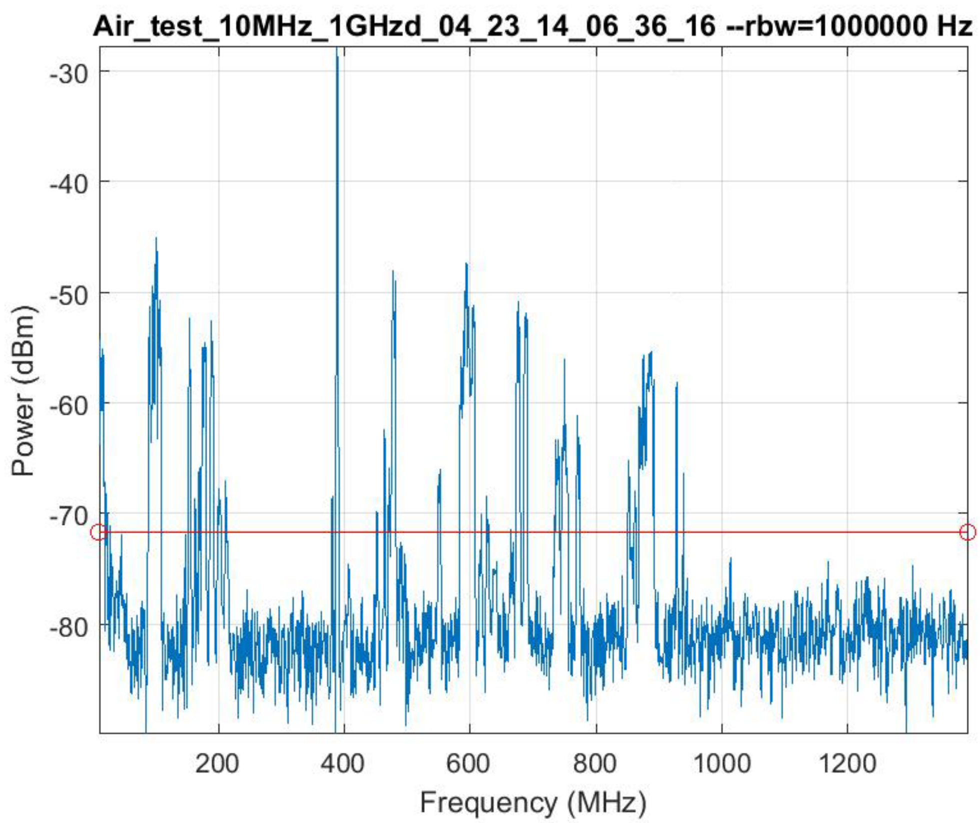

Air_test_4GHz_6GHzb_04_28_14_06_23_12 --rbw=10000 Hz
-85
-90
-95
-100
-105
-110
-115
Power (dBm)
4000
4500
5000
5500
6000
Frequency (MHz)

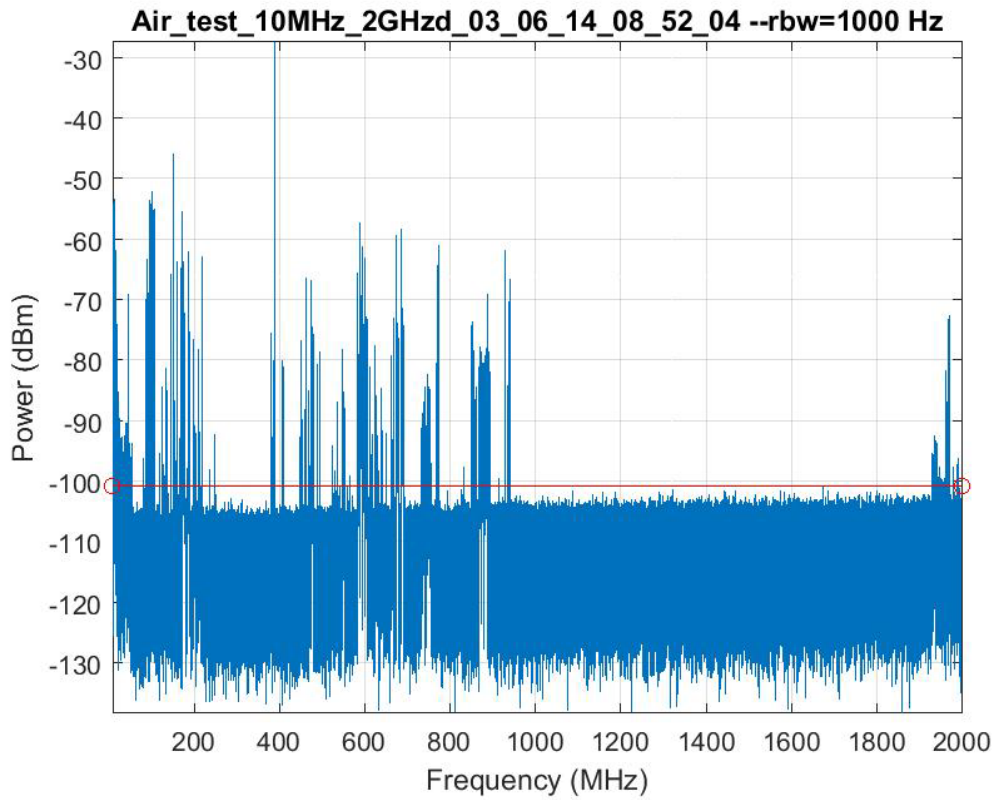

Air_test_4GHz_6GHzc_04_29_14_06_48_42 --rbw=100000 Hz
-80
-85
-90
-95
Power (dBm)
4000
4500
5000
5500
6000
Frequency (MHz)

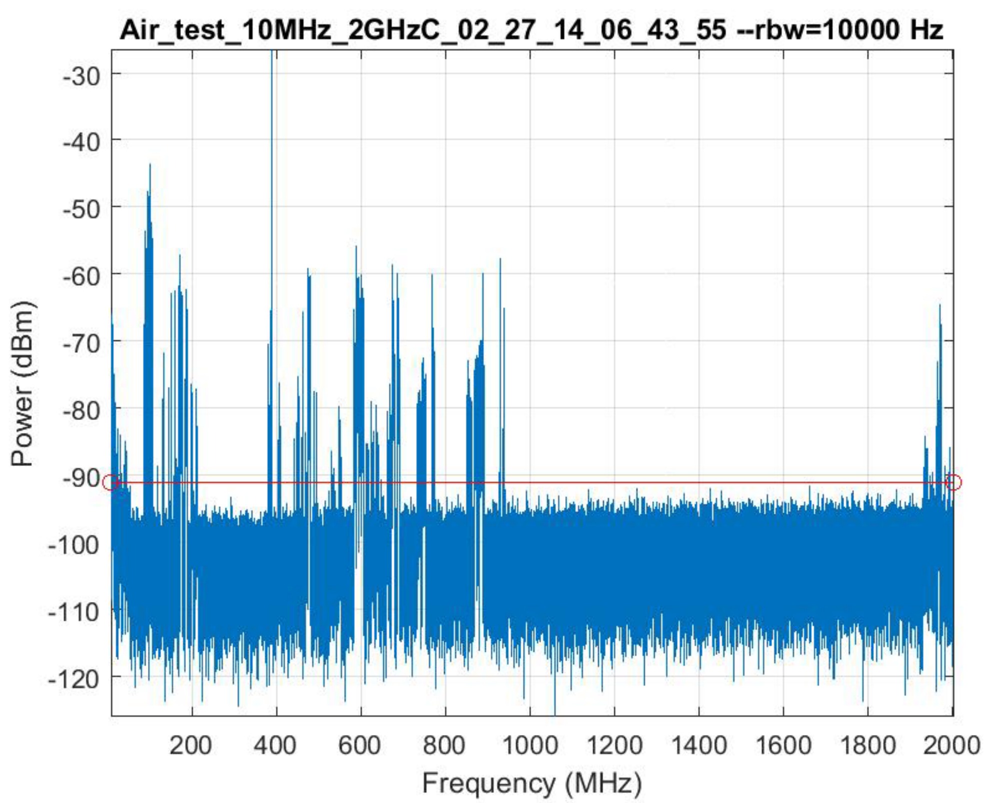

Air_test_10MHz_1GHza_04_17_14_07_09_30 --rbw=1000 Hz
Power (dBm)
Frequency (MHz)
-40
-60
-80
-100
-120
-140
100
200
300
400
500
600
700
800
900
1000

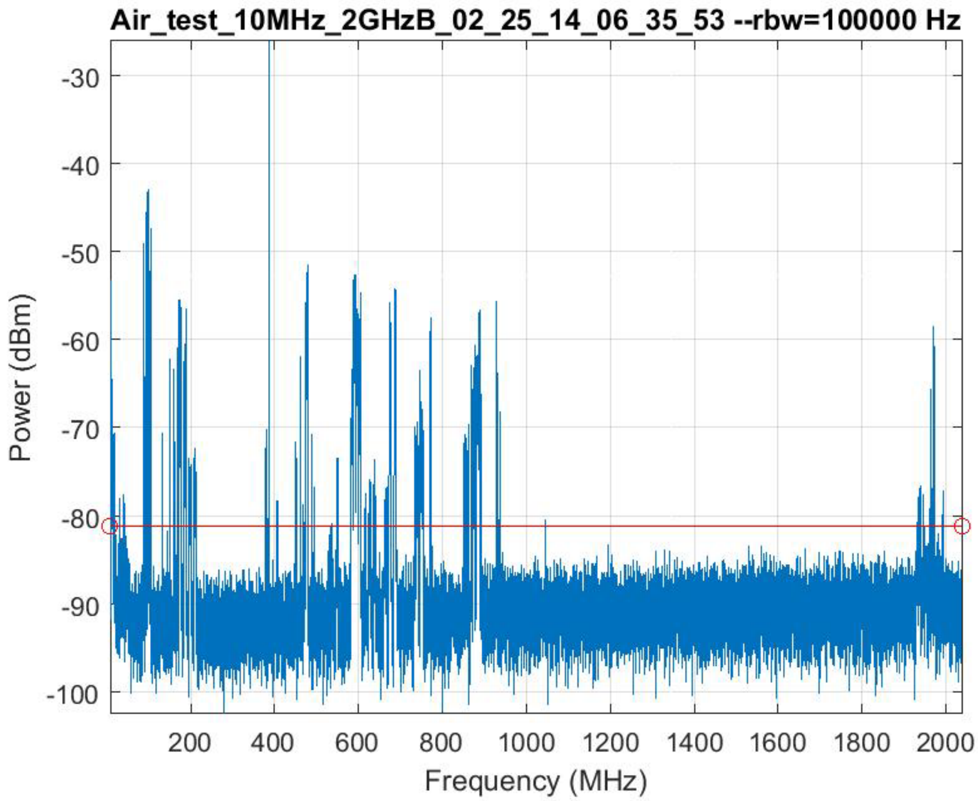

Air_test_10MHz_1GHzb_04_21_14_07_17_44 --rbw=10000 Hz
Power (dBm)
Frequency (MHz)
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
100
200
300
400
500
600
700
800
900
1000

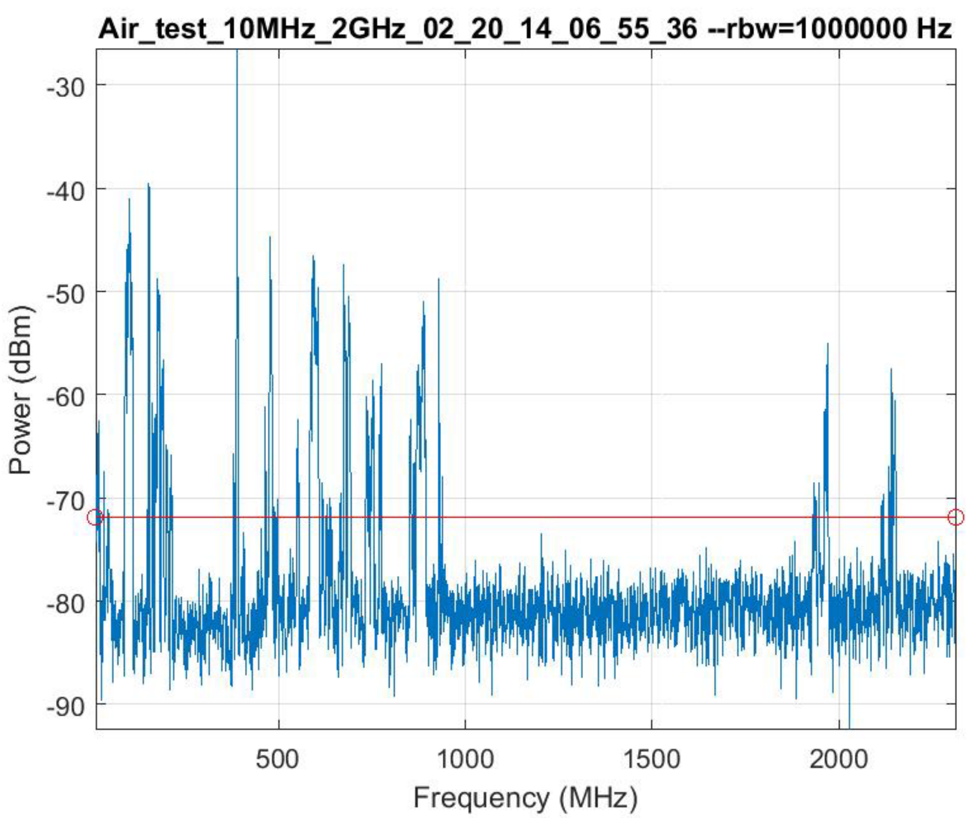

Air_test_10MHz_1GHzc_04_22_14_06_39_58 --rbw=100000 Hz
Power (dBm)
Frequency (MHz)
-30
-40
-50
-60
-70
-80
-90
-100
100
200
300
400
500
600
700
800
900
1000


Air_test_10MHz_1GHzd_04_23_14_06_36_16 --rbw=1000000 Hz
Power (dBm)
Frequency (MHz)
-30
-40
-50
-60
-70
-80
200
400
600
800
1000
1200

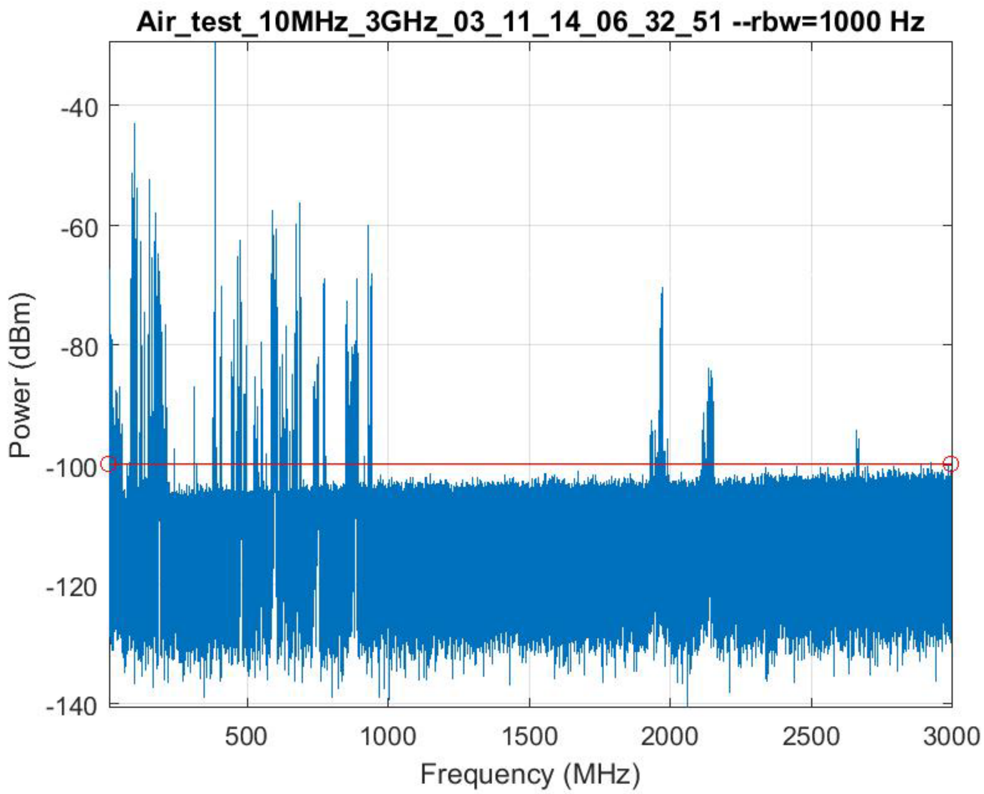

Air_test_10MHz_2GHzd_03_06_14_08_52_04 --rbw=1000 Hz
Power (dBm)
Frequency (MHz)

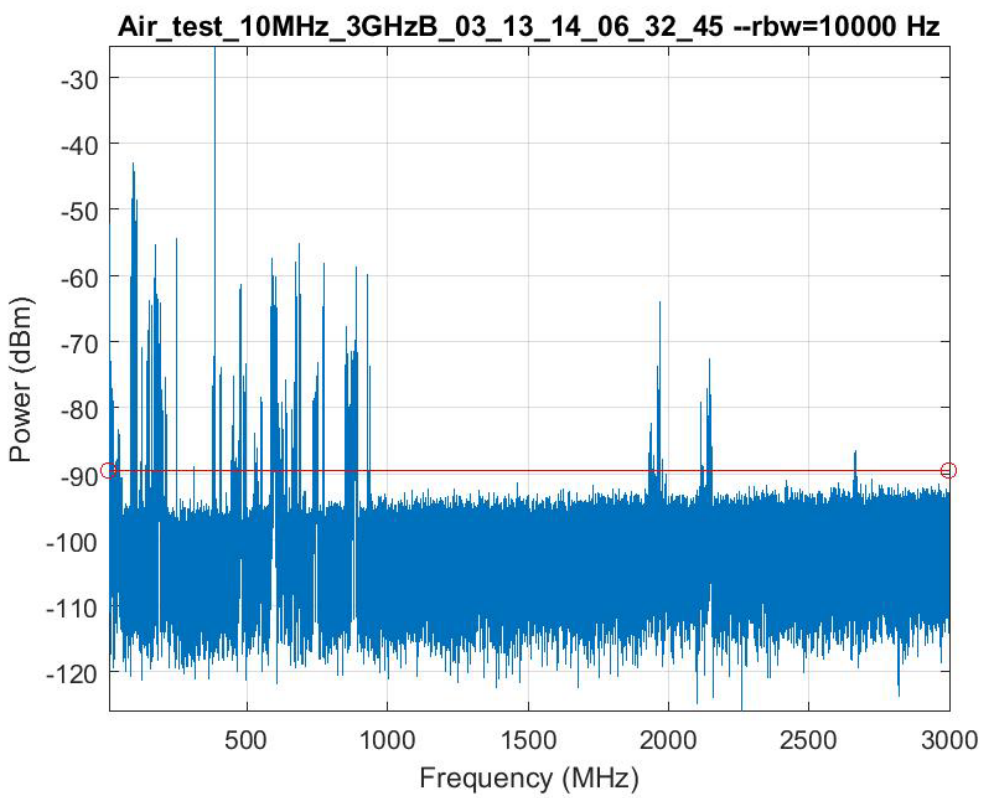

Air_test_10MHz_2GHzC_02_27_14_06_43_55 --rbw=10000 Hz
Power (dBm)
Frequency (MHz)



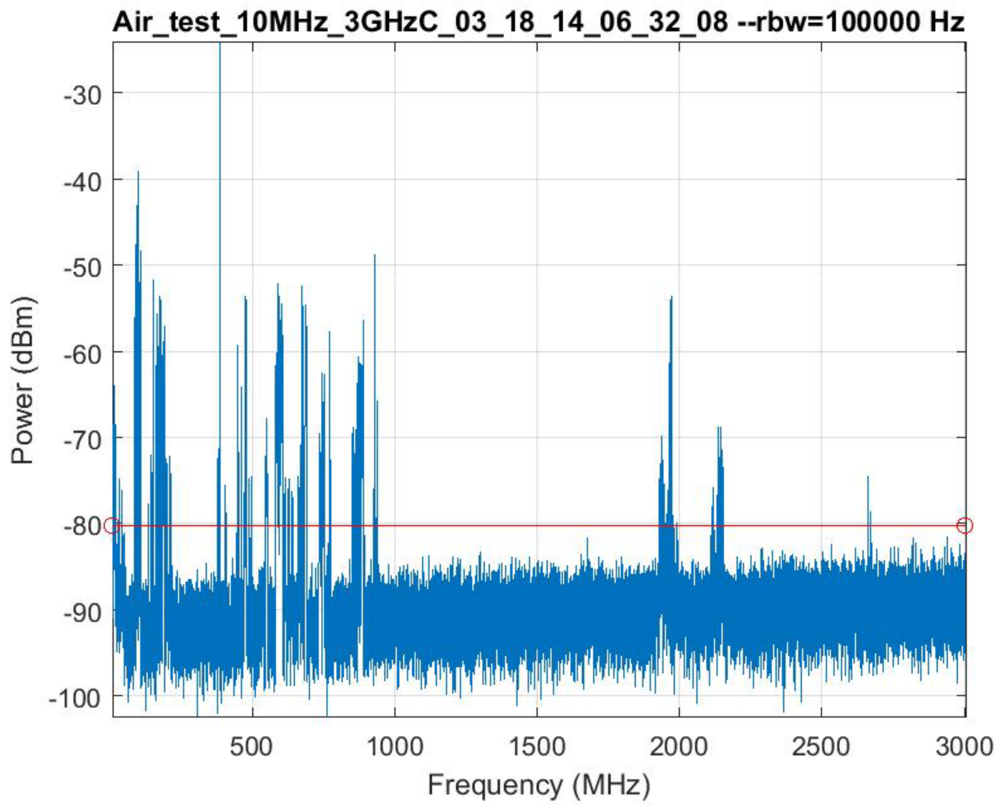


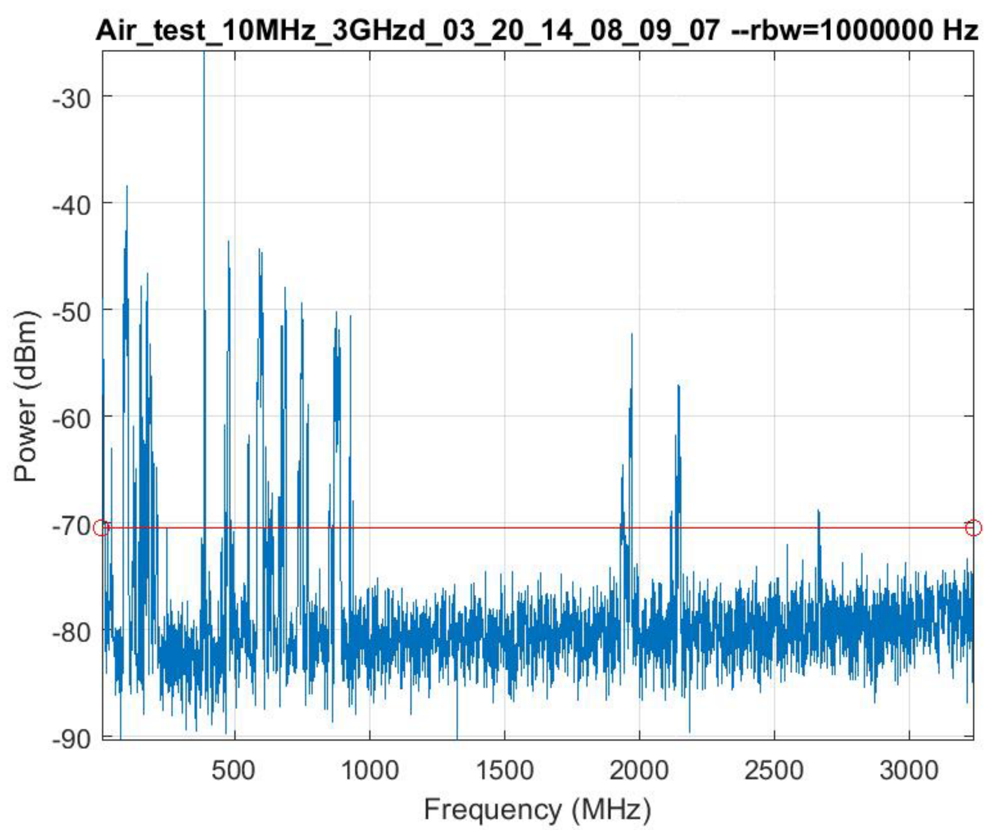
Approved for public release; distribution is unlimited.

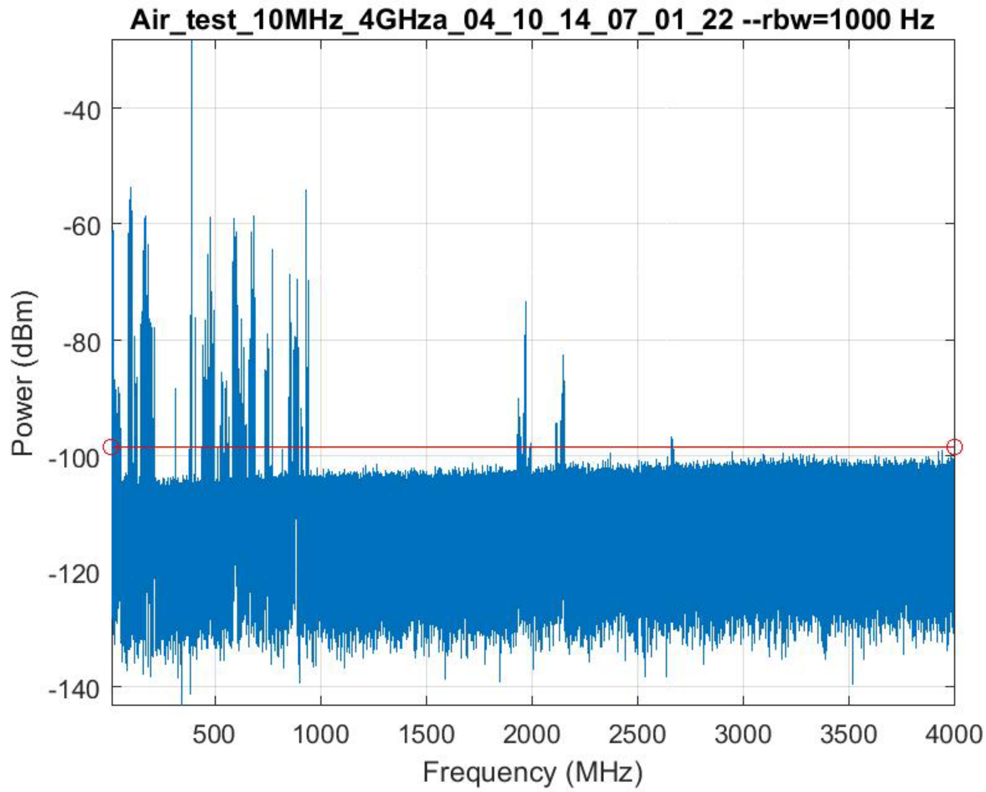


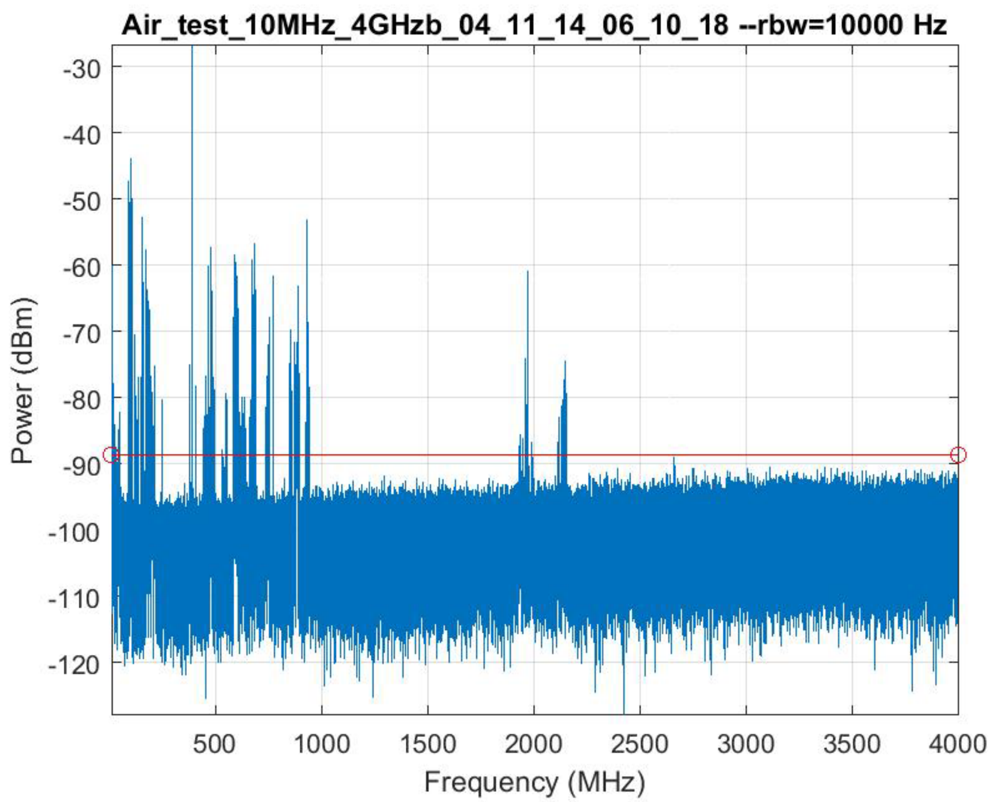


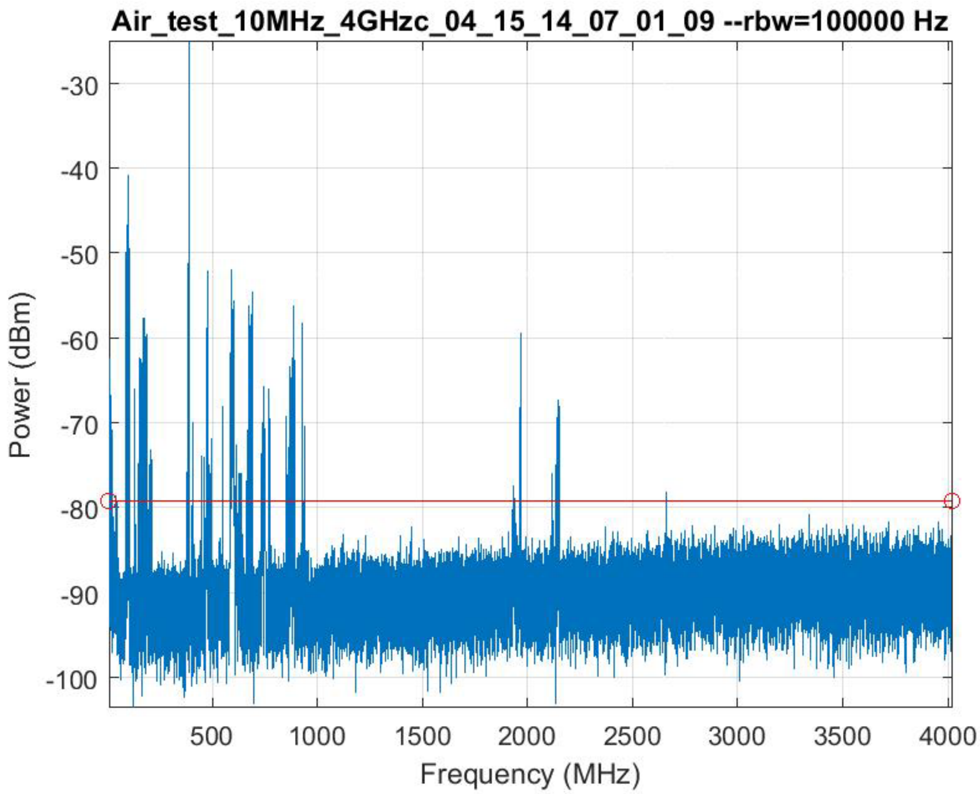
Approved for public release; distribution is unlimited.

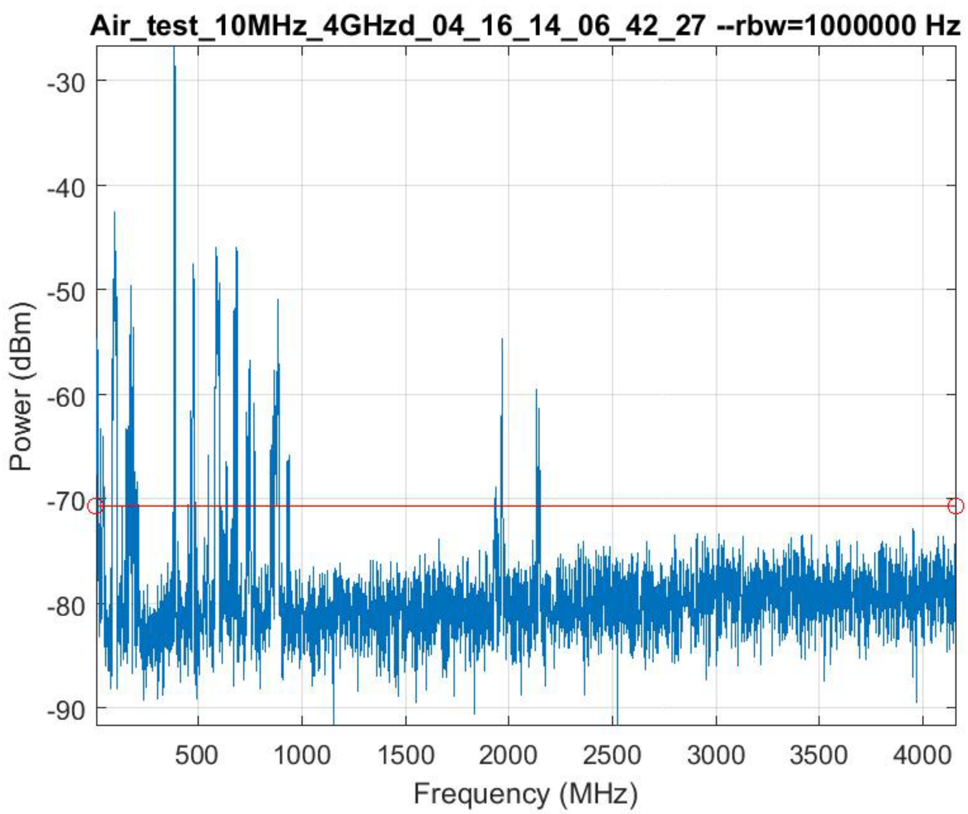

Air_test_10MHz_3GHzC_03_18_14_06_32_08 --rbw=100000 Hz
Power (dBm)
Frequency (MHz)
-30
-40
-50
-60
-70
-80
-90
-100
500
1000
1500
2000
2500
3000

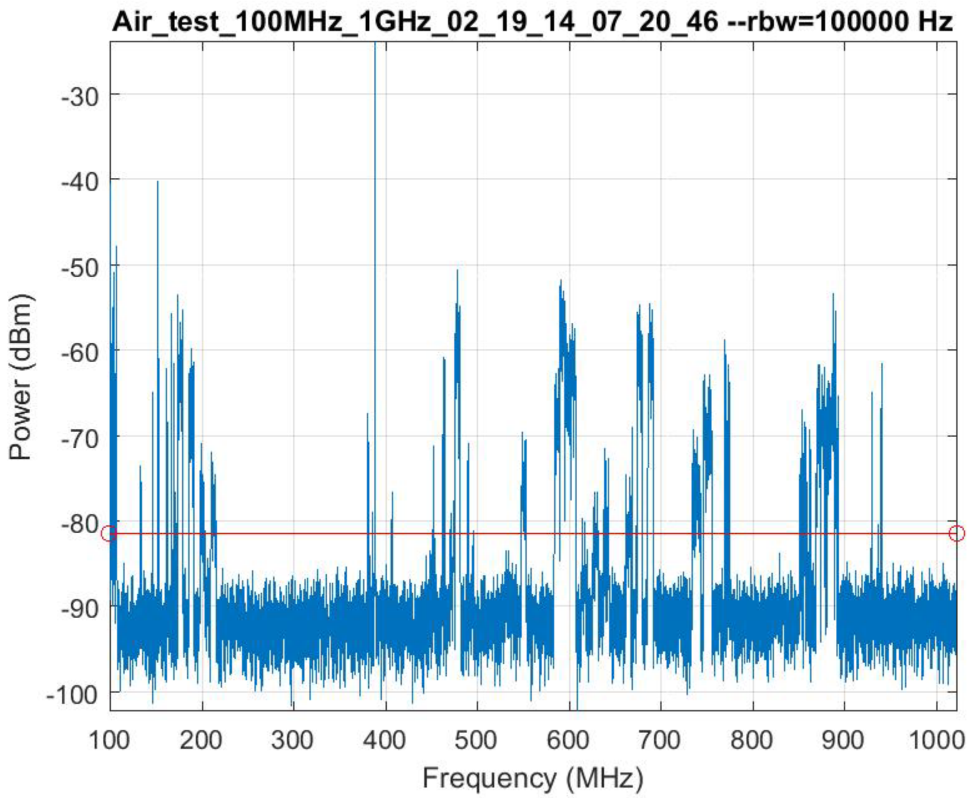

Air_test_10MHz_3GHzd_03_20_14_08_09_07 --rbw=1000000 Hz
Power (dBm)
Frequency (MHz)
-30
-40
-50
-60
-70
-80
-90
500
1000
1500
2000
2500
3000


Air_test_10MHz_4GHza_04_10_14_07_01_22 --rbw=1000 Hz
Power (dBm)
Frequency (MHz)
-40
-60
-80
-100
-120
-140
500
1000
1500
2000
2500
3000
3500
4000


Air_test_10MHz_4GHzb_04_11_14_06_10_18 --rbw=10000 Hz
Power (dBm)
Frequency (MHz)
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
500
1000
1500
2000
2500
3000
3500
4000


Air_test_10MHz_4GHzc_04_15_14_07_01_09 --rbw=100000 Hz
Power (dBm)
-30
-40
-50
-60
-70
-80
-90
-100
500
1000
1500
2000
2500
3000
3500
4000
Frequency (MHz)


Air_test_10MHz_4GHzd_04_16_14_06_42_27 --rbw=1000000 Hz
Power (dBm)
-30
-40
-50
-60
-70
-80
-90
500
1000
1500
2000
2500
3000
3500
4000
Frequency (MHz)


Air_test_100MHz_1GHz_02_19_14_07_20_46 --rbw=100000 Hz
Power (dBm)
Frequency (MHz)
-30
-40
-50
-60
-70
-80
-90
-100
100
200
300
400
500
600
700
800
900
1000

List of Symbols, Abbreviations, and Acronyms

ARL	US Army Research Laboratory
CF	crest factor
GHz	gigahertz
kHz	kilohertz
MHz	megahertz
PDF	probability density function
RBW	resolution bandwidth
RF	radio frequency

1 (PDF)	DEFENSE TECHNICAL INFORMATION CTR DTIC OCA
2 (PDF)	DIR ARL IMAL HRA RECORDS MGMT RDRL DCL TECH LIB
1 (PDF)	GOVT PRINTG OFC A MALHOTRA
7 (PDF)	ARL RDRL SER E M CONN R DEL ROSARIO K F TOM D WASHINGTON RDRL SER M J SILVIOUS RDRL SER U A MARTONE RDRL SER W K RANNEY

INTENTIONALLY LEFT BLANK.